

ERNEST ORLANDO LAWRENCE BERKELEY NATIONAL LABORATORY

ESTIMATING RISK TO CALIFORNIA ENERGY INFRASTRUCTURE FROM PROJECTED CLIMATE CHANGE

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Environmental Energy Technologies Division

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ACKNOWLEDGEMENTS

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ABSTRACT

A decorative horizontal border consisting of a repeating pattern of small, square, hollow rectangles.

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A horizontal row of 20 small squares, each containing a vertical bar pattern.

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TABLE OF CONTENTS

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LIST OF FIGURES

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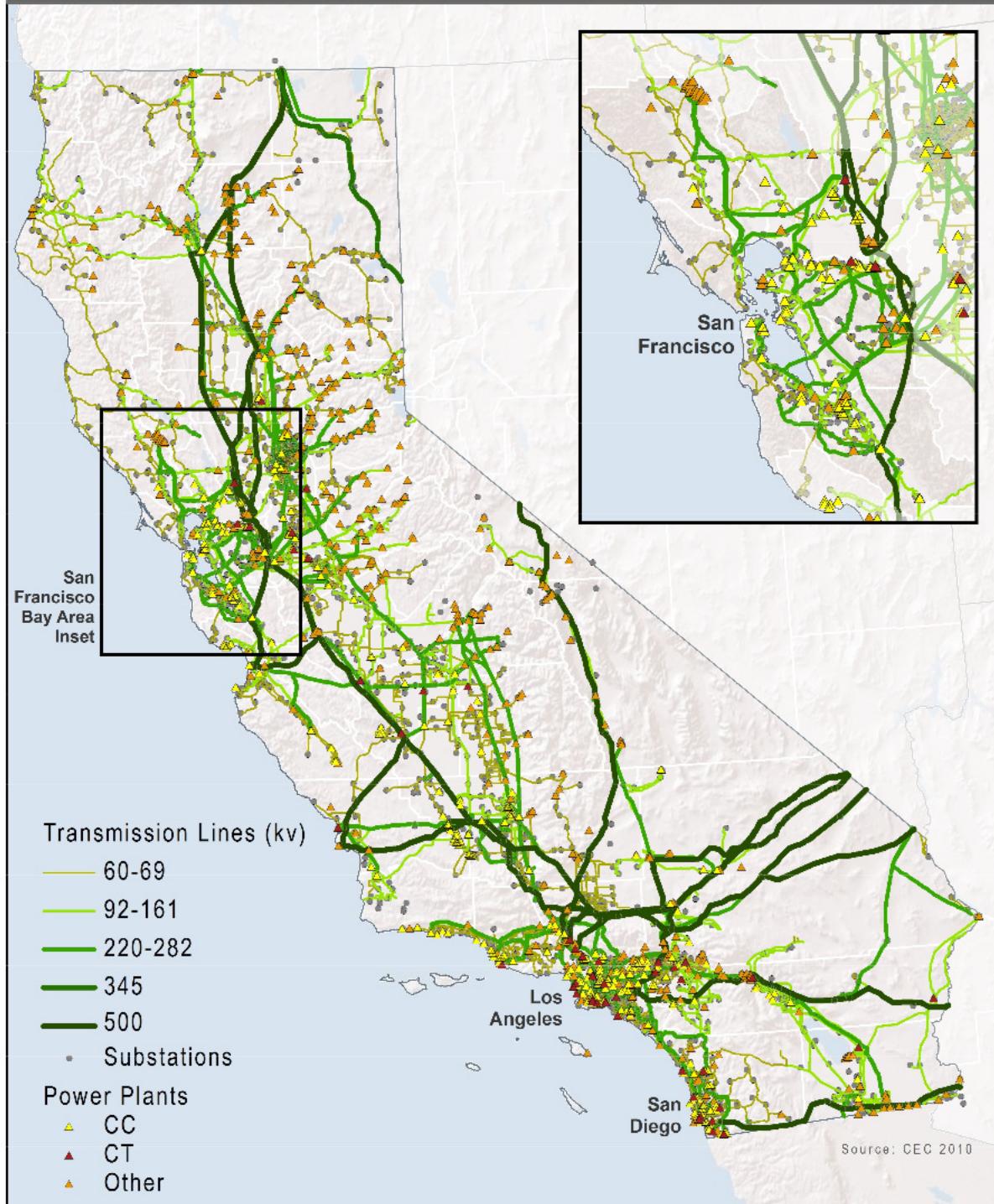
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LIST OF TABLES

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The image consists of ten horizontal rows of data. Each row is represented by a sequence of small, light-gray square blocks arranged side-by-side. The rows are evenly spaced vertically. The total width of the data is approximately 900 pixels, and the height of each row is about 10 pixels.

California's Major Power Infrastructure



EXECUTIVE SUMMARY

Introduction

Purpose

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Objectives

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Conclusions and/or Recommendations

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CHAPTER 1: Introduction

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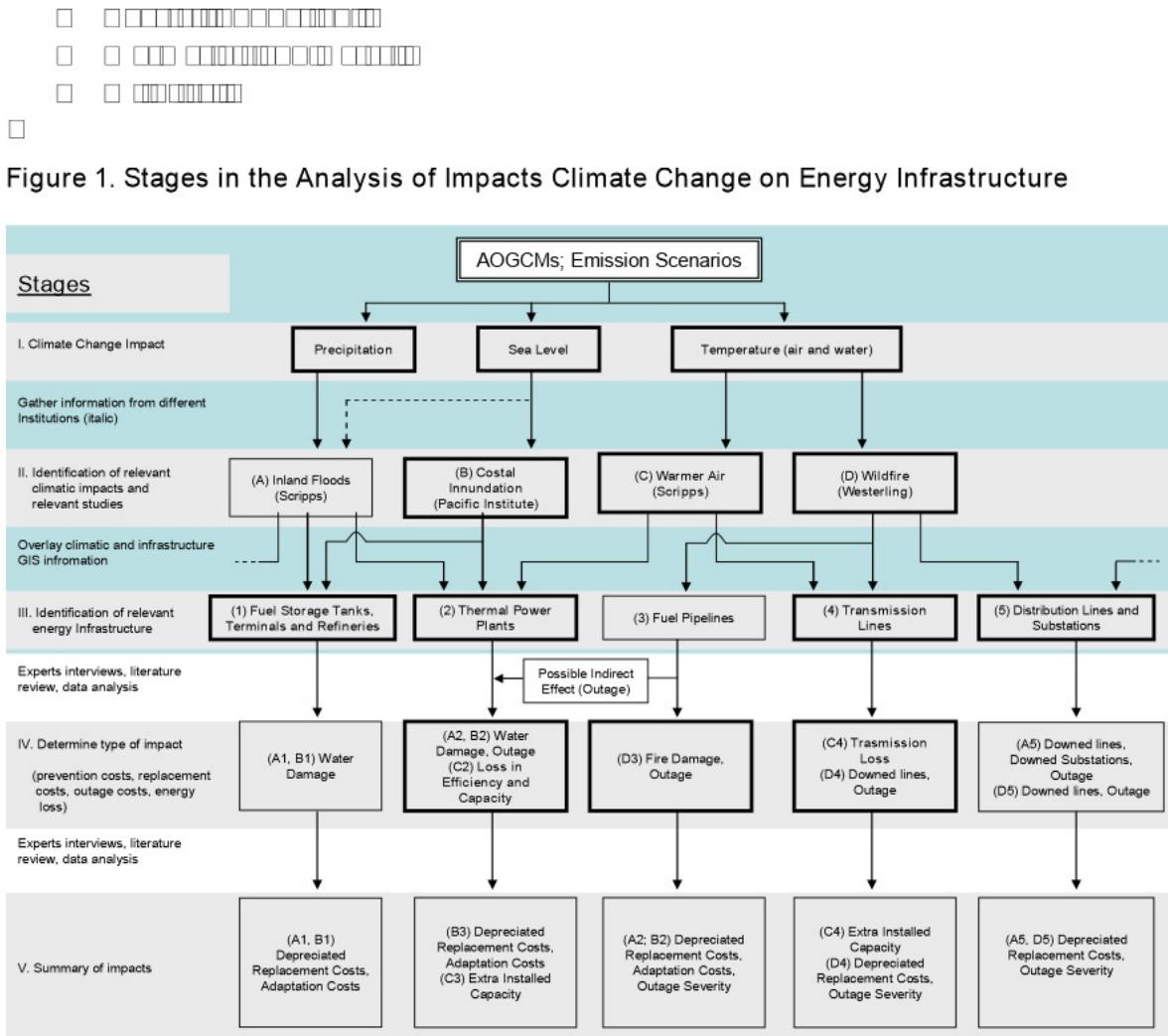
A horizontal row of ten empty rectangular boxes, intended for students to write their answers in during a test or assignment.

A horizontal row of 15 small squares, each divided vertically into two equal halves. The first square is entirely white. The second square has its left half white and its right half gray. This pattern repeats across all 15 squares.

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9. **What is the primary purpose of the following statement?**



Preliminary Results: Do not cite or reference.

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Climate Model Projections

Warming Temperatures

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Increased Wildfire Incidence, Severity, and Range

Sea-level Rise/ Coastal Inundation

California's Peak Period Electricity Infrastructure

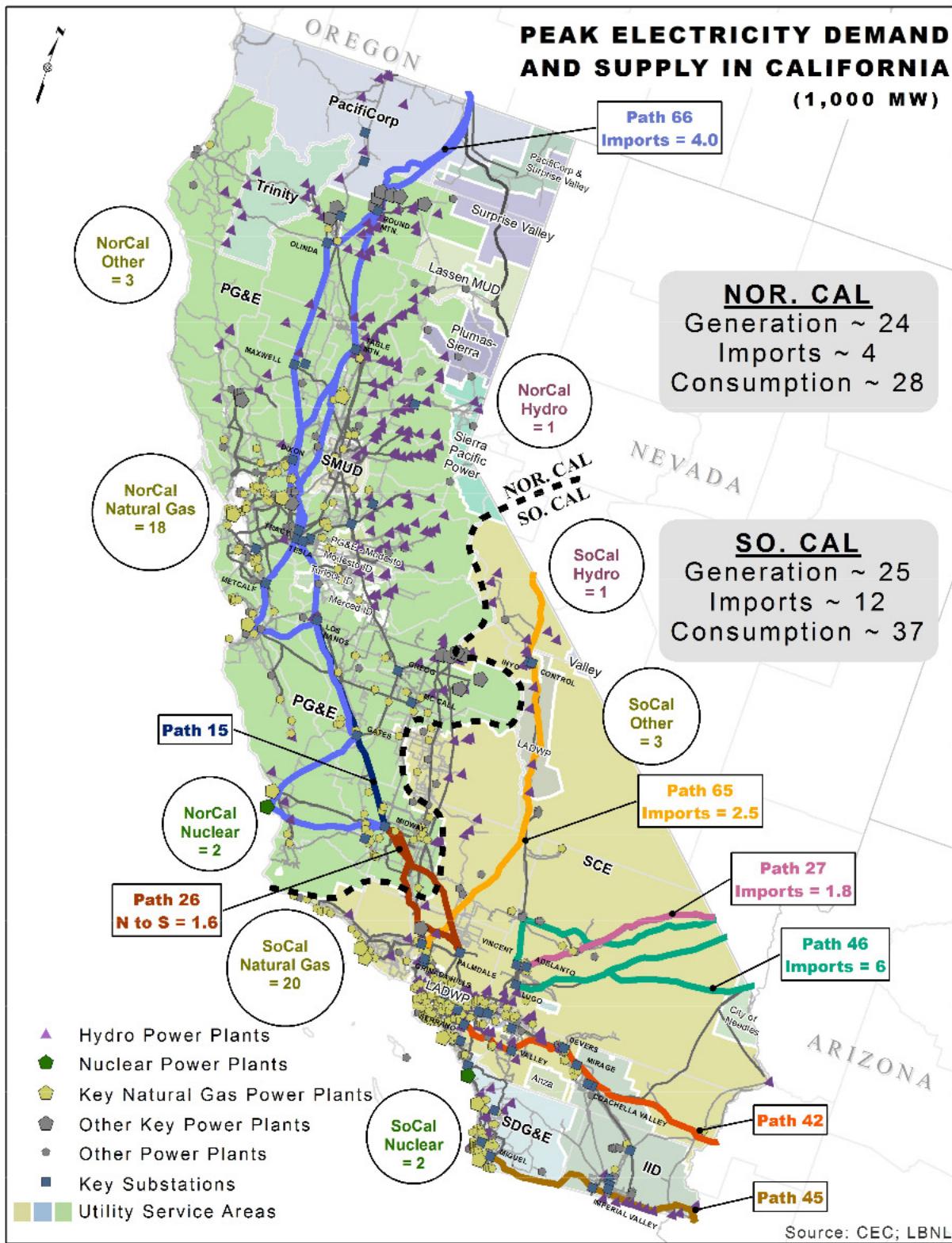
A large grid of small squares, likely a placeholder or a decorative background.

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Figure 2. Peak Electricity Demand and Supply in California



Chapter 2:

Impact of Temperature on Power Plants, Substations, and Transmission Lines □

Methodological Overview

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Importing Energy Infrastructure Data and Merging Local Maximum Temperature Projections

Projected Impacts to Natural Gas-Fired Power Plant Capacity

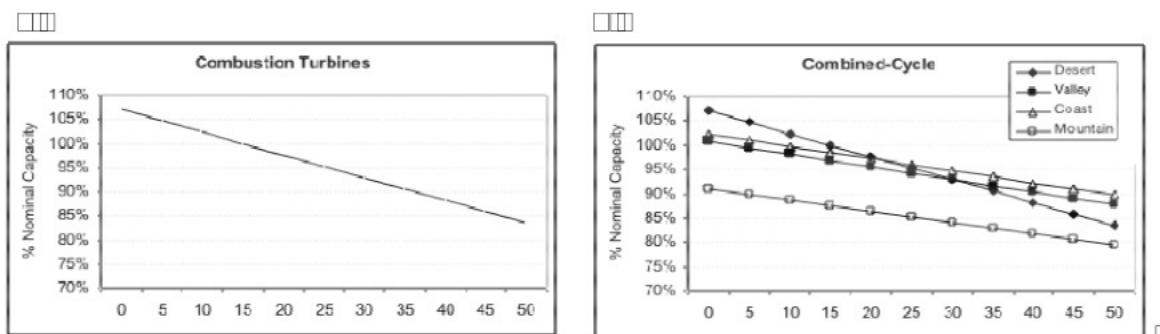


Figure 3. Change in Turbine Capacity as a Function of Ambient Temperature (Maulbetsch and DiFilippo 2006; Kehlhofer et al. 2009).

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Relating Power Plant Capacity to Ambient Temperature

Summary of Key Model Assumptions

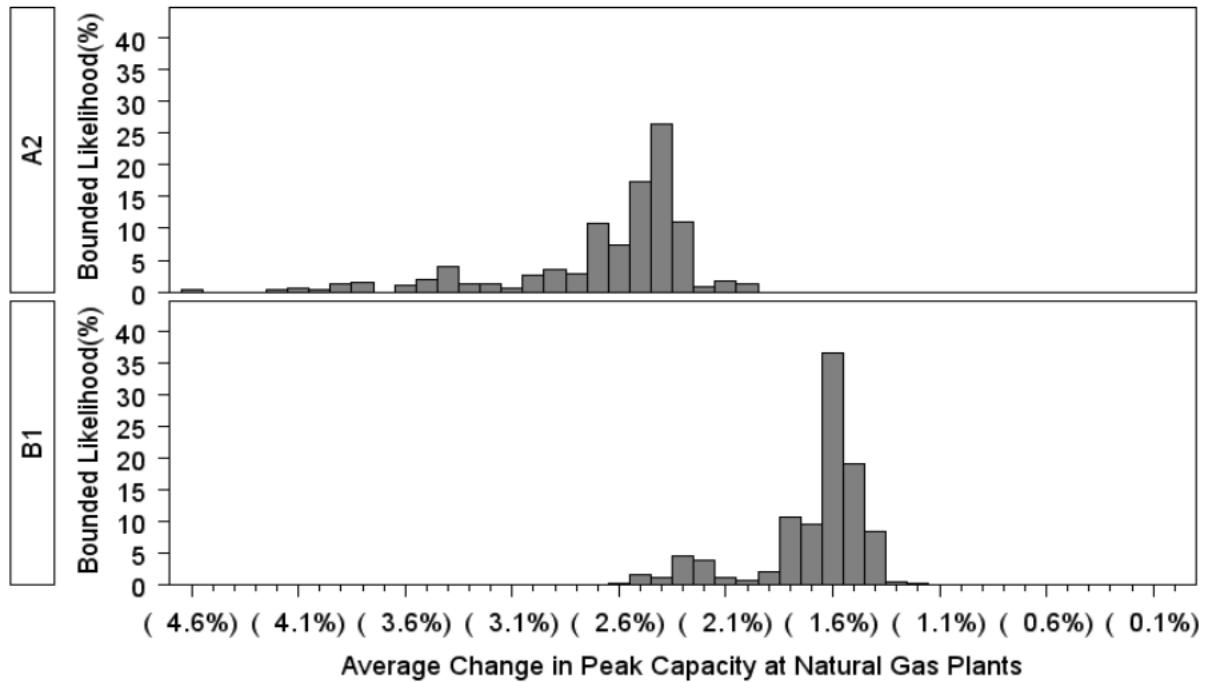
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Table 1. Key Assumptions for Natural Gas Power Plant Analysis

Preliminary Results

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Three AOGCMs: 2070-2099



NOTES: Distribution based on results from three AOGCMs for 2070-2099 time period.

Figure 4. Probability of Changes in Peak Capacity at California Natural Gas Power Plants Between Current Period and End of Century

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□ 田中　和也　（たなか　かずや）　1972年　福岡県　生まれ。福岡市立大野小学校、福岡市立大野中学校、福岡市立大野高等学校卒業。福岡市立大野高等学校では、音楽部に所属。高校時代は、主にギターを弾いていたが、大学時代から、主にベースを弾くようになり、現在はベースを中心に活動している。また、ギターも弾きこなす。音楽部では、主にベース担当だったが、他の楽器も弾きこなす。音楽部では、主にベース担当だったが、他の楽器も弾きこなす。

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A2 Scenario, Three AOGCMs Average Peak Capacity Loss in August

Source: Scripps; CEC; LBNL

CC Power Plants

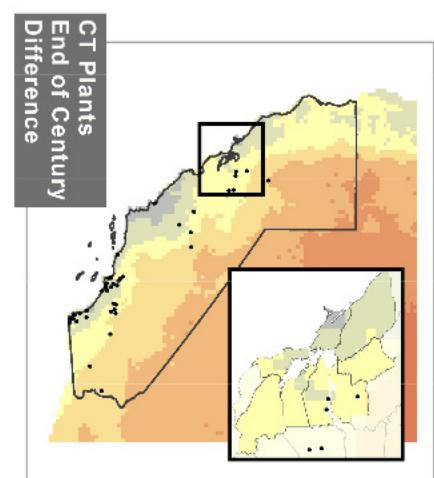
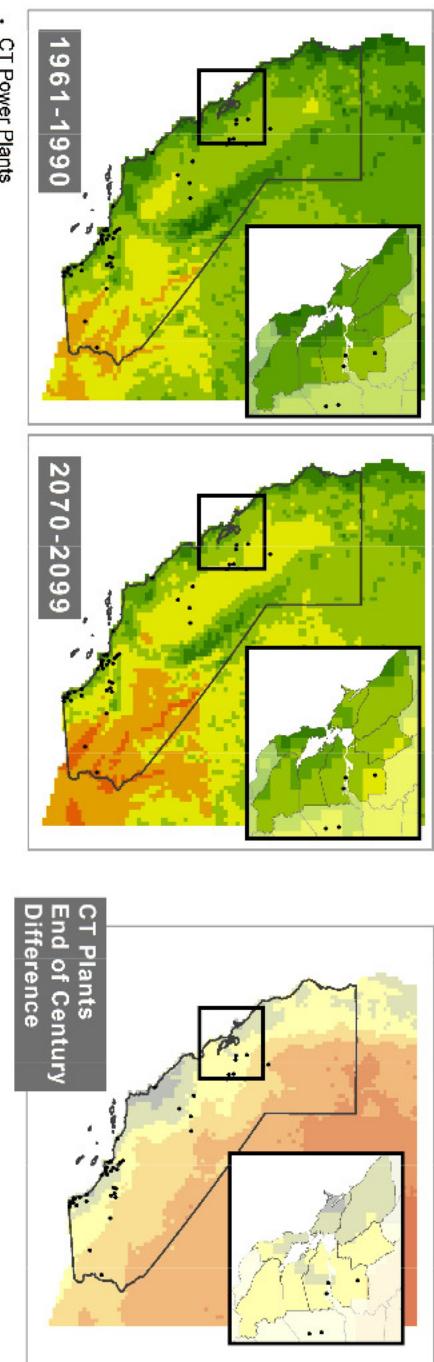
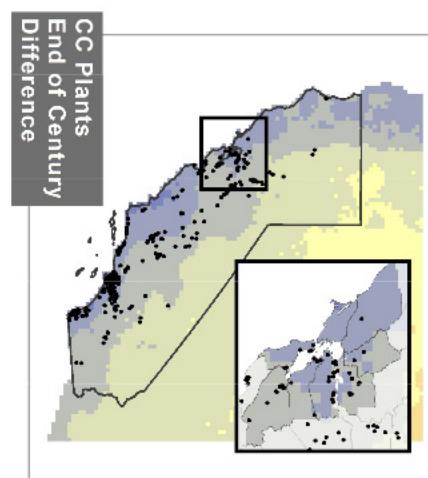
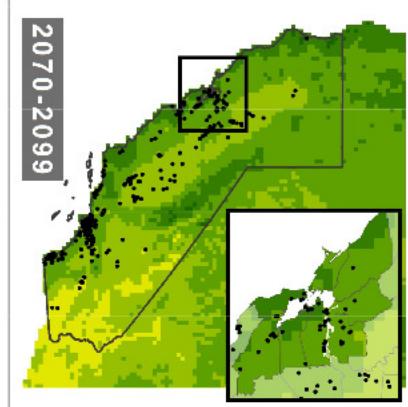
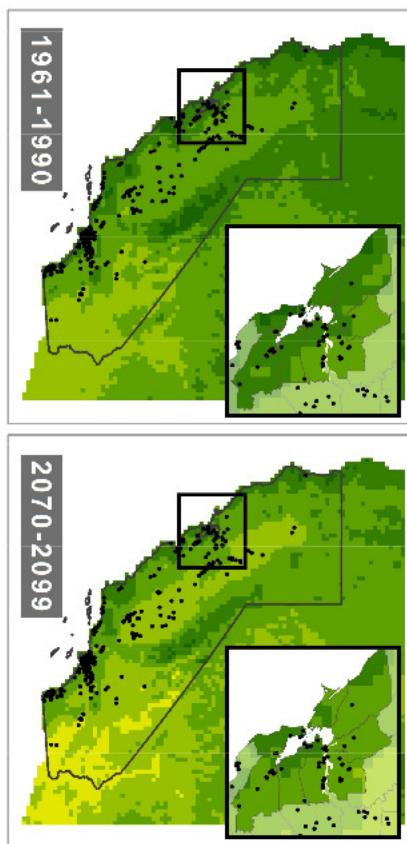


Figure 5. Projected Change to Natural Gas-fired CT Power Plant Peak Capacity: Average August loss for each period, taken over three AOGCMs under the A2 scenario

A2 Scenario, Three AOGCMs Maximum Peak Capacity Loss in August

CC Power Plants

Source: Scripps; CEC; LBNL

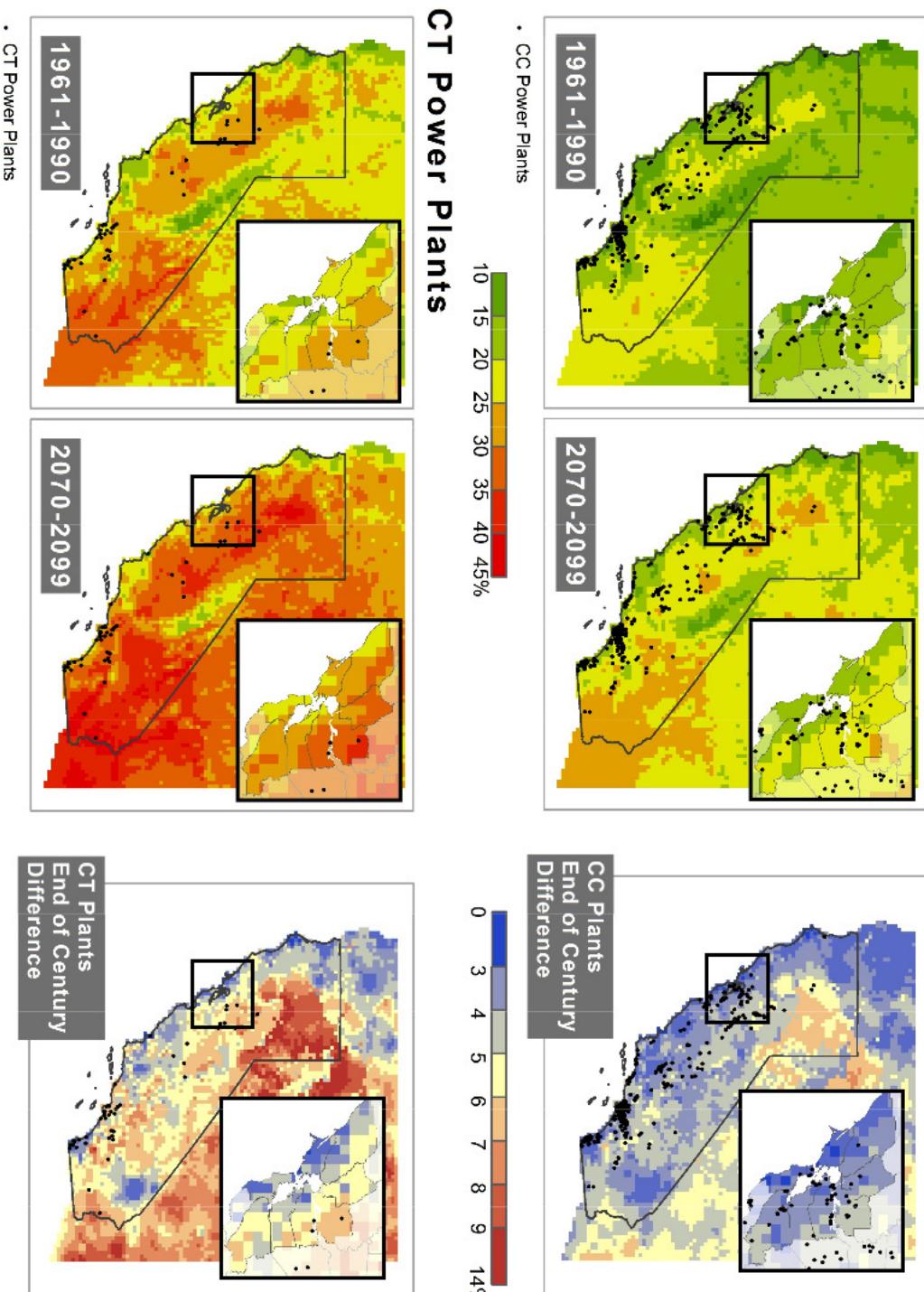


Figure 6. Projected Change to Natural Gas-fired CT Power Plant Peak Capacity: Maximum August loss for each period, taken over three AOGCMs under the A2 scenario

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Table 2a & 2b. Maximum and average A2 and B1 coincident statewide peak capacity loss (weekdays) at gas-fired power plants. (Percentage total is the fraction of the total state gas-fired generating capacity of 44.1 GW.)

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Projected Impacts to Substation/Transformer Capacity

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Relating Substation/Transformer Capacity to Ambient Temperature



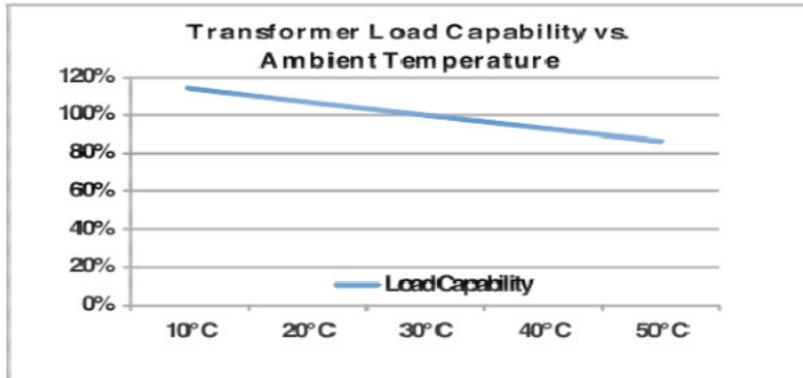
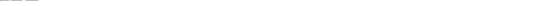
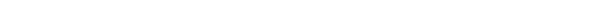
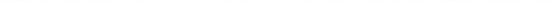
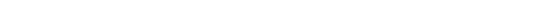
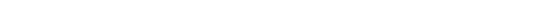
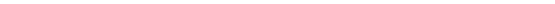
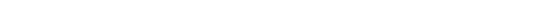
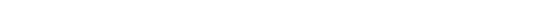
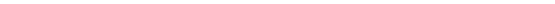
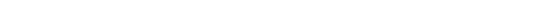
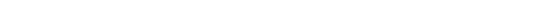
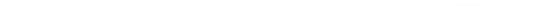
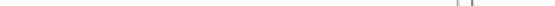
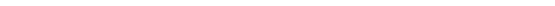
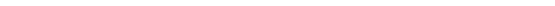
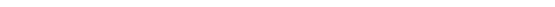
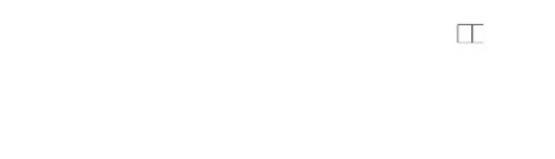
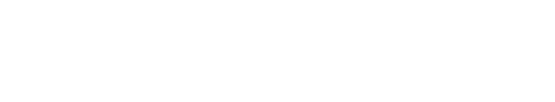


Figure 7. Change in Transformer Capacity as a Function of Ambient Temperature
 (adapted from Li et al. 2005).

Summary of Key Model Assumptions

Table 3. General Substation Capacity Model Assumptions

	
	
 	
	
	
	
	
	
	
	
	
	
	
	
	
	
	
	
	
	
	
	
	
	
	
	
	
	
	
	
	
	
	
	
	
	
	
	
	
	
	
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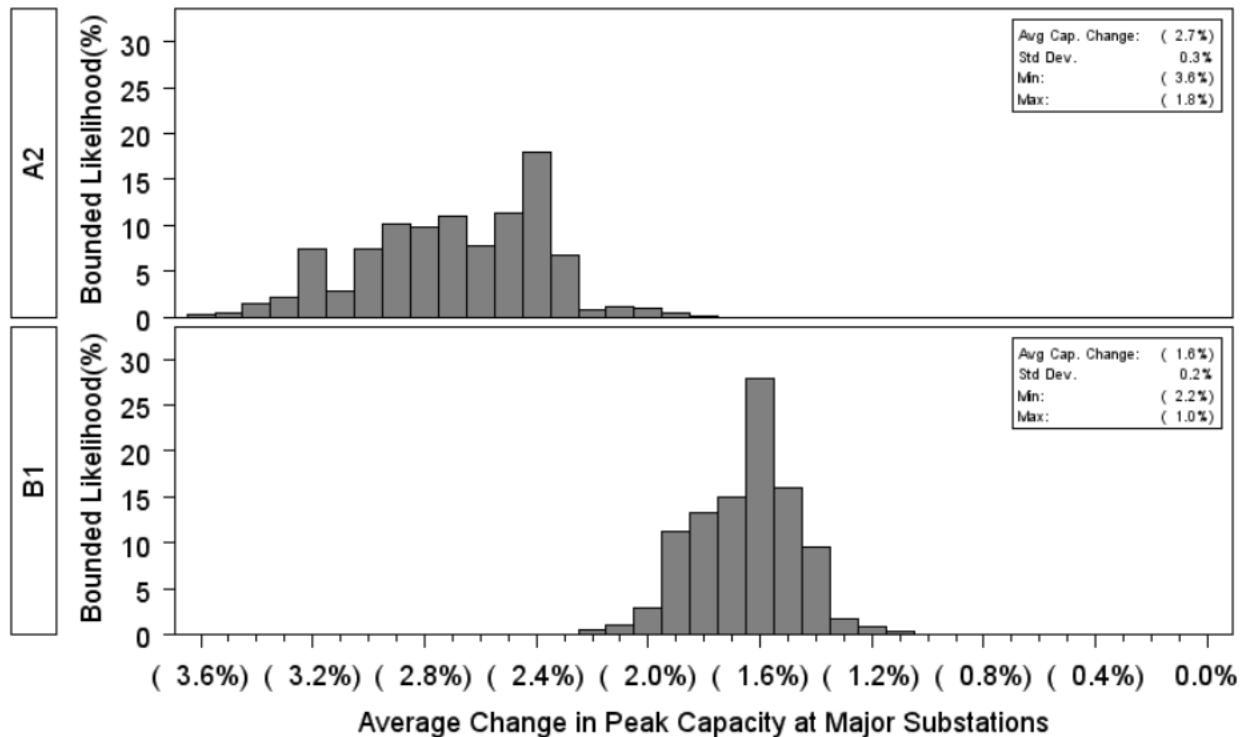
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Preliminary Results

Figure 8. Average Changes in Peak Capacity at California Substations (2070-99)

August Daily Maximum Temperature

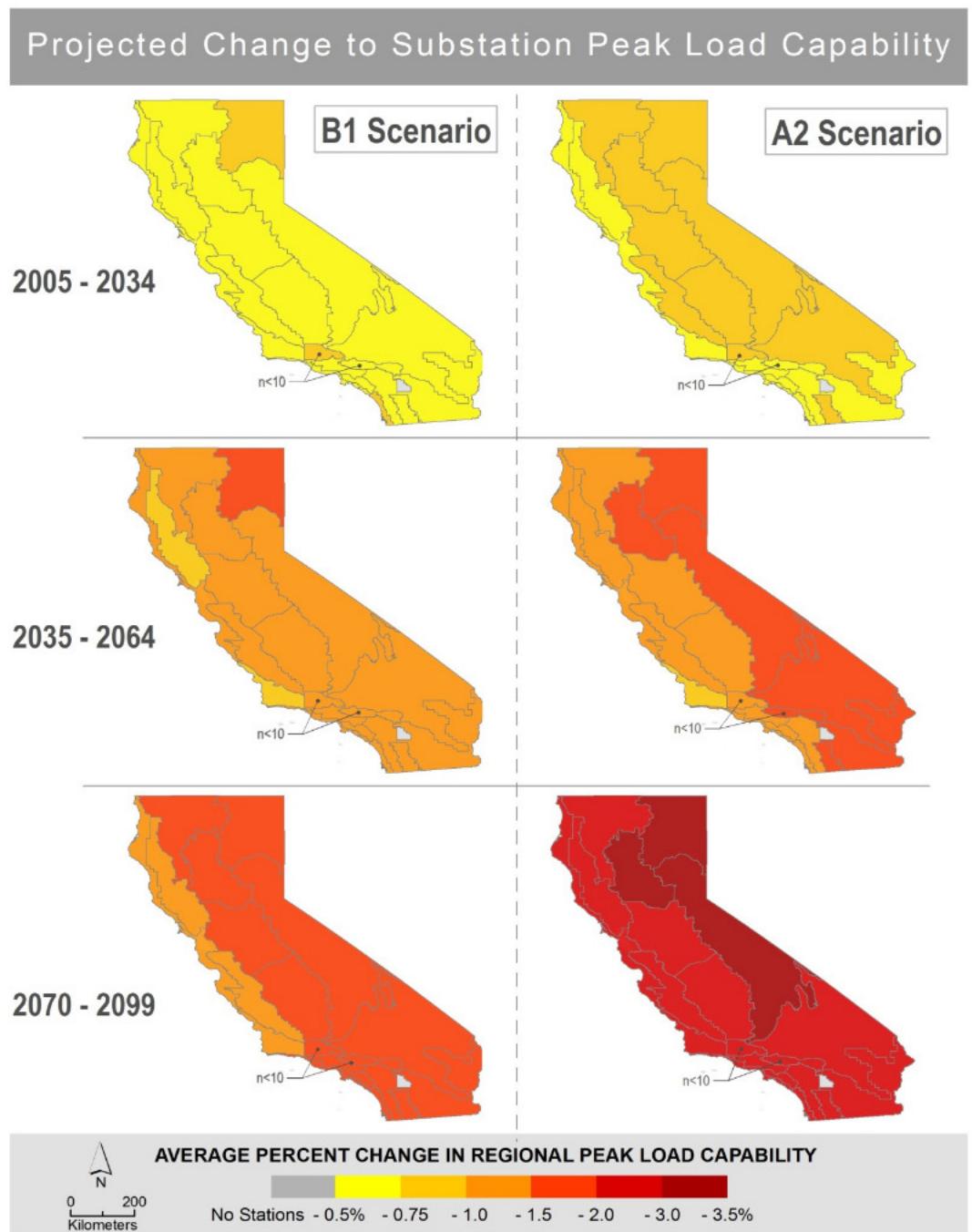
Three AOGCMs: 2070-2099



NOTES: Distribution based on results from three AOGCMs for 2070-2099 time period.

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Figure 9. Projected Average Change to Regional Substation Capacity



Projected Impacts to Transmission Line Carrying Capacity

Relating Transmission Carrying Capacity to Ambient Temperature

Summary of Key Model Assumptions

Table 4. Key Assumptions for Transmission Analysis

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Preliminary Results

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Table 5. Sample Transmission Line Parameters

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Table 6. Conductor Temperature and Line Loss under Hot Ambient Conditions

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Table 7. Ambient Temperature and Conductor Capacity Loss. (Conductor temperature held constant at 80°C by reducing line current.)

Projected Impacts to Transmission and Distribution Efficiency

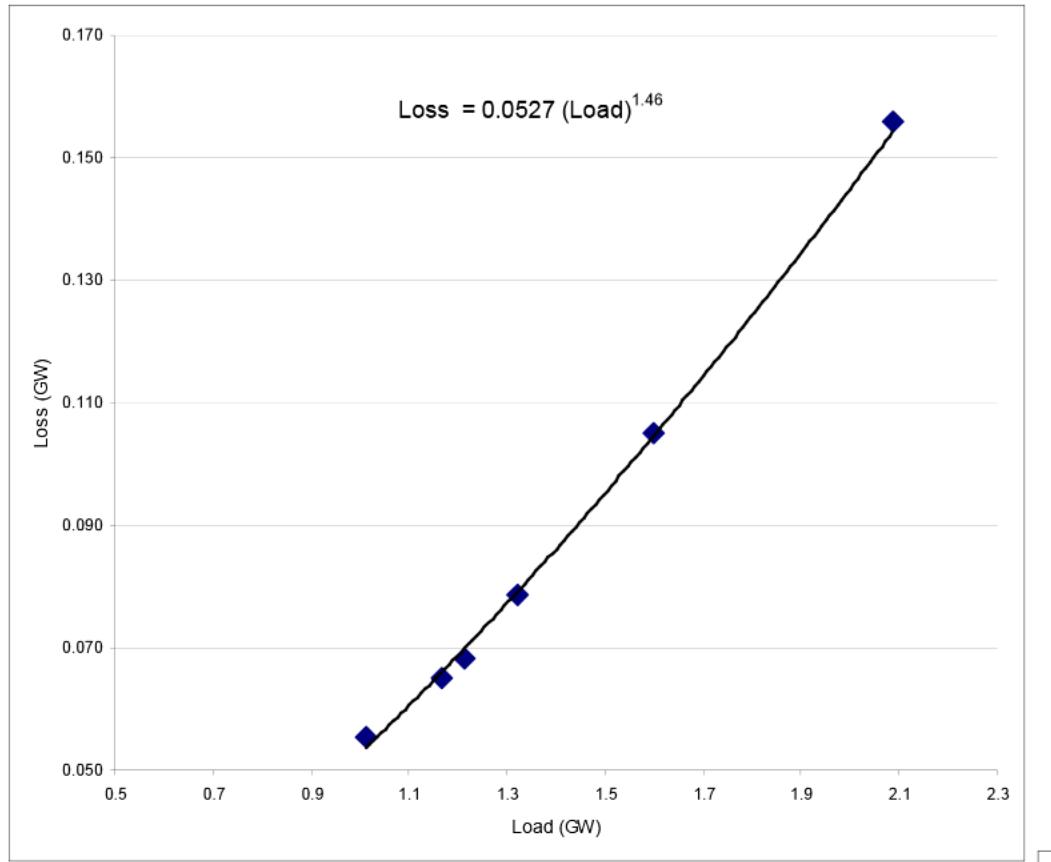
Table 8. System Average Loss Factors

Period	Average temperature (Farenheit)	Load (MW)	Transmission loss factors (%)	Distribution loss factors (%)	Total loss factors (%)
Summer Super Peak	85.5	2088.4	2.0	5.5	7.5
Summer On-Peak	79	1600.3	1.7	4.9	6.6
Summer Off-Peak	66.9	1213.6	1.5	4.2	5.6
Spring	60.9	1167.9	1.4	4.1	5.6
Winter On-Peak	53.8	1319.9	1.5	4.4	6.0
Winter Off-Peak	45.9	1011.3	1.4	4.1	5.5

Source: Sacramento Municipal Utility District planning document. 2000

Figure 10. System Load and System Losses

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Implications for Utilities and Potential Future Research

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The image consists of a large grid of small, uniform squares arranged in horizontal rows. The grid is composed of approximately 100 columns and 15 rows. Each row contains a different pattern of squares, creating a visual effect similar to a barcode or a stylized representation of binary data. The patterns vary from mostly solid black to mostly solid white, with some intermediate shades and vertical stripes.

Chapter 3:

Cumulative Effects of Temperature-Induced Losses

The image consists of eight horizontal rows of small, empty square boxes. These boxes are arranged in a grid-like pattern, with each row containing approximately 20-25 boxes. The rows are evenly spaced and extend across the width of the frame. The boxes are white with thin black outlines, giving them a clean, minimalist appearance.

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Demand

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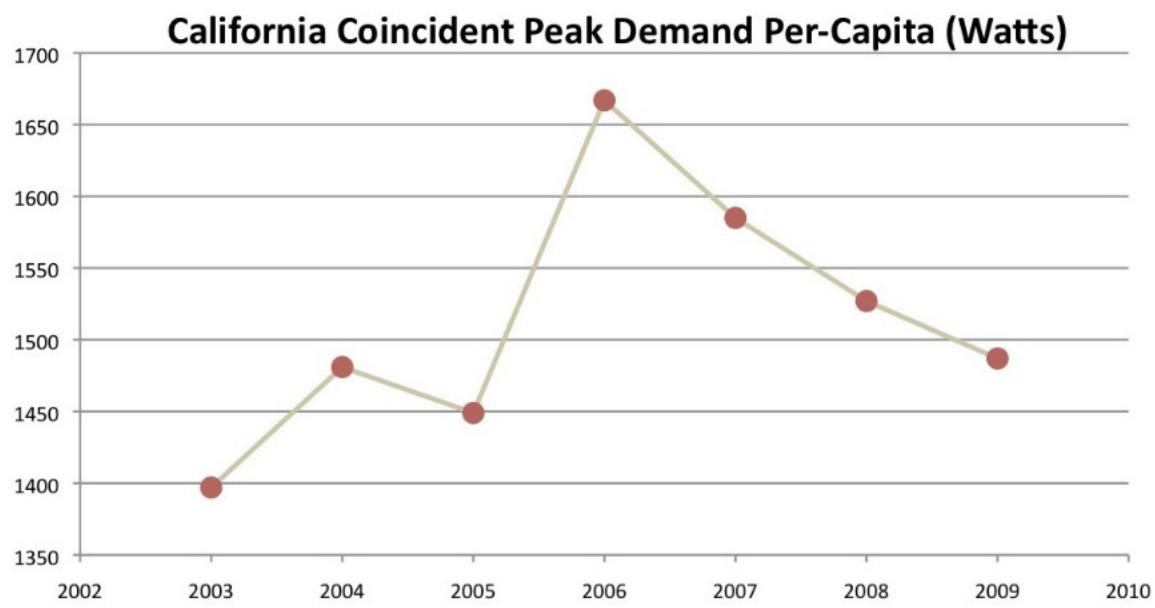
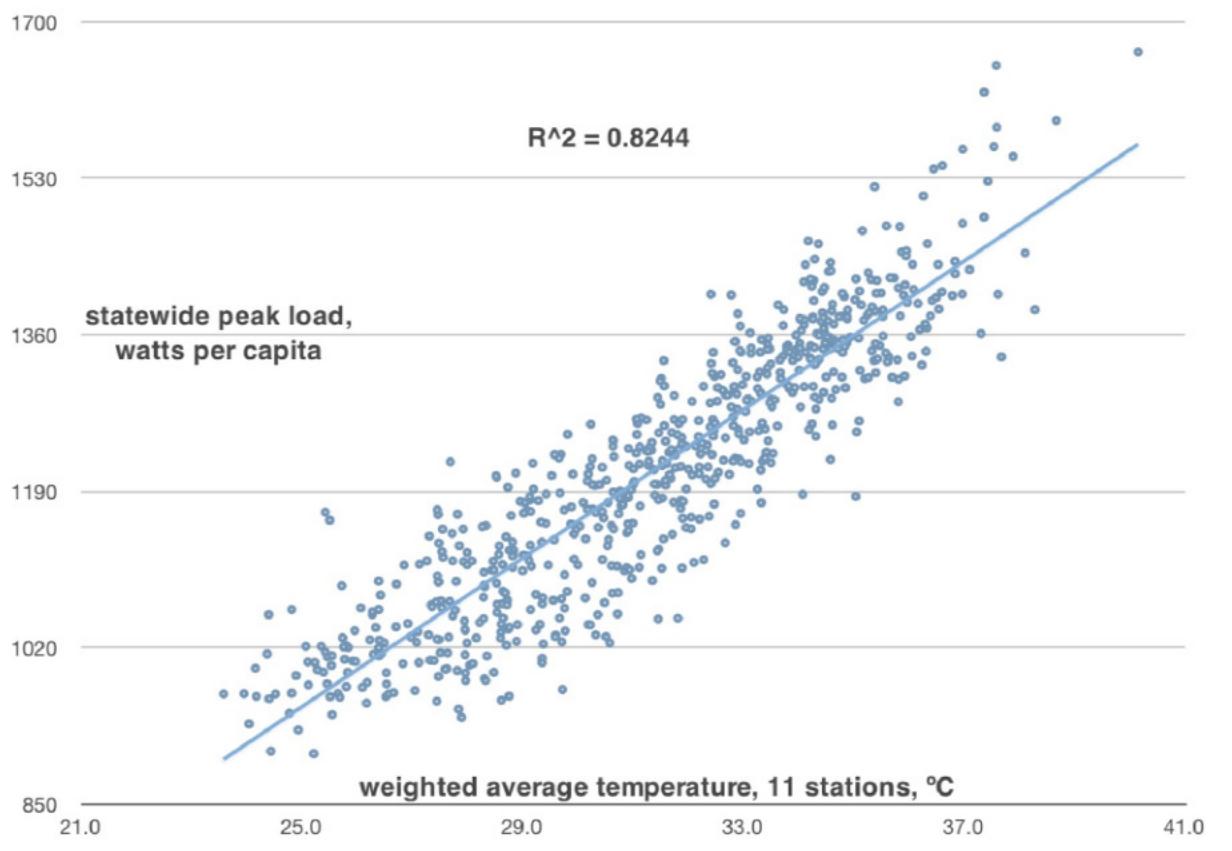


Figure 11. Maximum yearly peak demand, statewide per-capita





Figure 12. CIMIS weather stations used to project statewide peak load. Numbers in Figure identify the weather stations.



□

□ Figure 13. Weighted average temperatures from the 11 CIMIS stations
versus actual statewide per-capita peak load, 2003 □ 2009

□

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	Statewide August Peak Load Per Capita (watts)							
	Mean	□ (%)	Days > 1,254 (%)	90th percentile	□ (%)	Days > 1,387 (%)	Max	□
Actual 2003-2009	1,254		50	1,387		10	1585	
CNRM/A2 2070-2099	1,532	22	98	1,661	20	94	1,930	22 %
GFDL/A2 2070-2099	1,552	24	100	1,683	21	88	1,851	17 %
PCM1/A2 2070-2099	1,490	19	93	1,585	14	67	1,778	12 %
CNRM/B1 2070-2099	1,449	16	96	1,571	13	82	1,720	9%
GFDL/B1 2070-2099	1,490	19	97	1,613	16	73	1,795	13 %
PCM1/B1 2070-2099	1,405	12	89	1,529	10	55	1,678	6%

Table 9. Statewide August peak load per-capita

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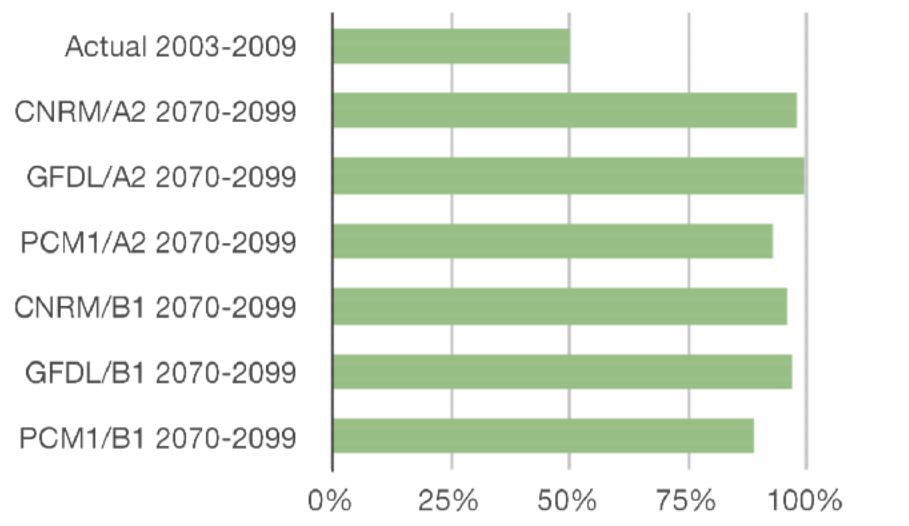


Figure 14. August days with peak loads > average August peak 2003-2009

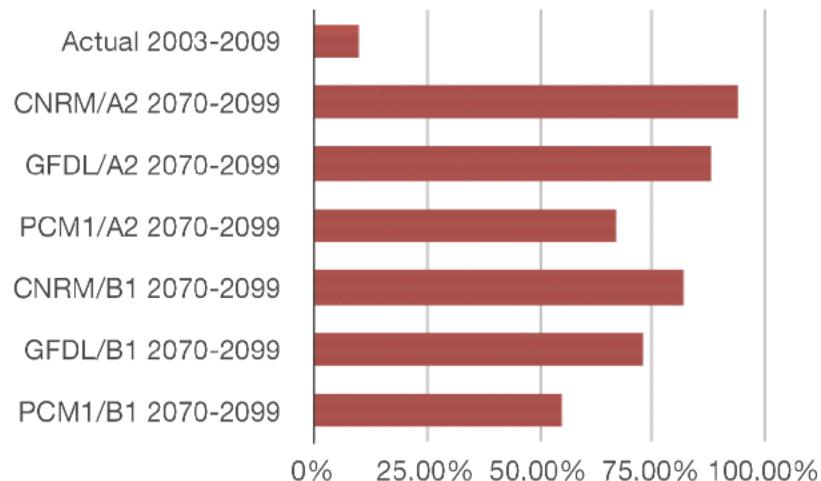


Figure 15. August days with peak loads > 1-in-10 August peak 2003-2009

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Cumulative Effect of Demand and Generation on Peak Load



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Watts per capita	1961-1990 1-in-10 total demand	2070-2099 1-in-10 total demand	□	2070-2099 days > 1961-1990 1-in-10
GFDL/A2	1541	1875	22%	93%
CNRM /A2	1490	1857	25%	93%
PCM1 /A2	1534	1748	14%	68%
GFDL /B1	1497	1696	13%	59%
CNRM /B1	1494	1654	11%	48%
PCM1 /B1	1500	1593	6%	25%

Table 10. Total statewide peak demand plus temperature-induced generation losses, in watts per capita⁹

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Summary and Implications for Utilities

ANSWER The answer is 1000.

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Caveats

Chapter 4:

Projected Wildfire Risk to Electricity Transmission

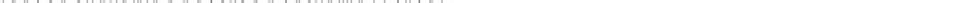


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Projected Wildfire Risk and Transmission Lines (Westerling Dataset)

A large grid of small squares, likely a 10x10 or 11x11 grid, used for counting practice.

Methods

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Results

A grid of 10 rows and 10 columns of small squares, representing a 10x10 matrix.

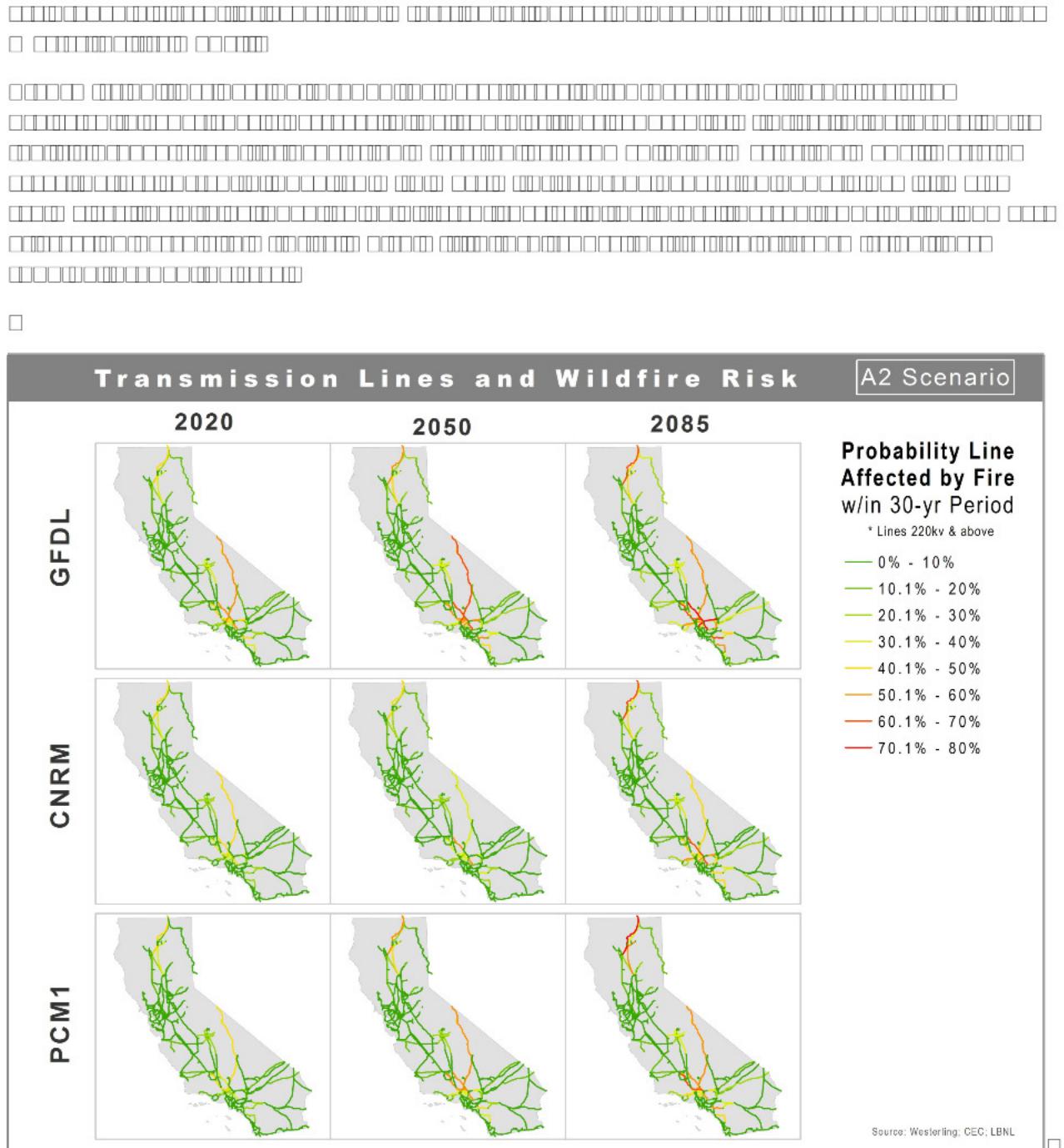


Figure 16. Projected fire risk to transmission lines for the A2 scenario

Transmission Lines and Wildfire Risk

B1 Scenario

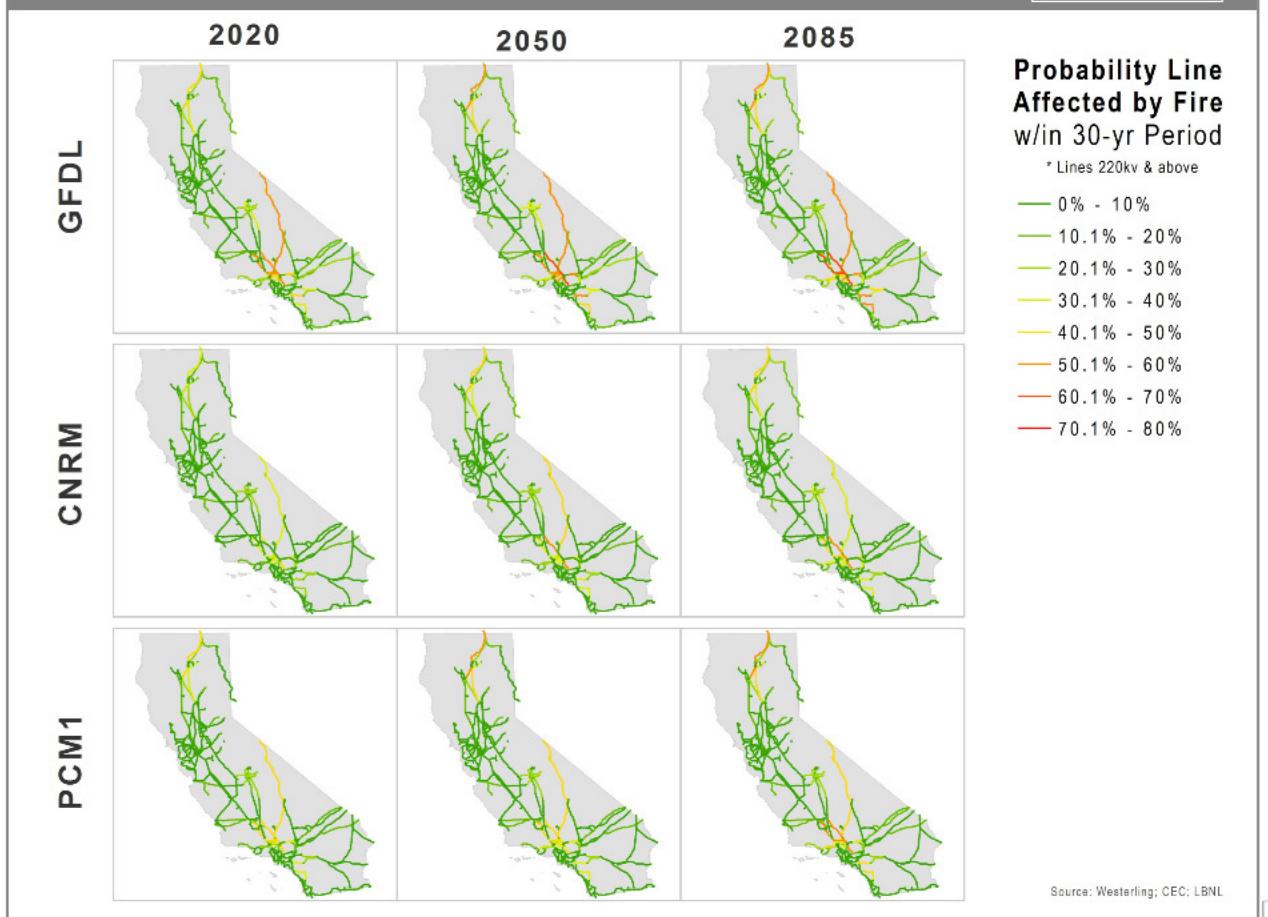


Figure 17. Projected fire risk to transmission lines for the B1 scenario.

End of century change in the probability a wildfire affects a transmission line

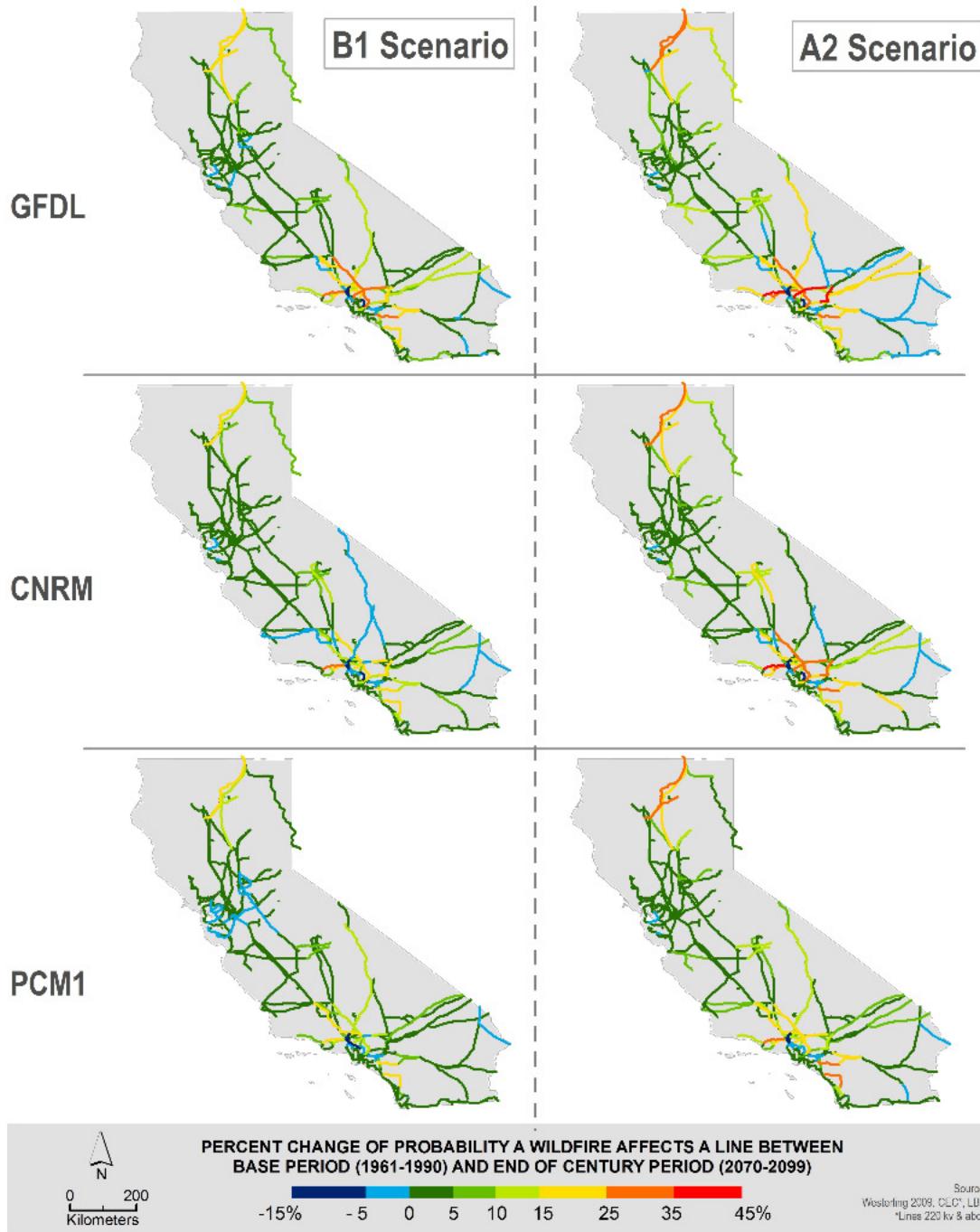


Figure 18. Whole-line exposure to wildfire risk

Implications for Utilities and Next Steps

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Chapter 5:

Impact of Sea Level Rise/ Coastal Inundation

Projected Power Plant Impacts

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Power Plants Potentially at Risk from Sea Level Rise

At-Risk Power Plants

(MW)	
●	0 - 10
●	11 - 50
●	51 - 150
●	151 - 250
●	251 - 2000

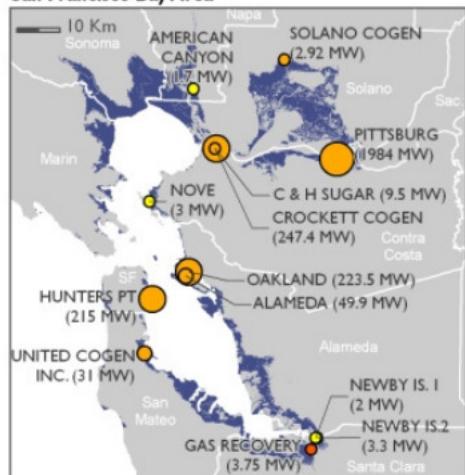
Fuel

- OIL/GAS
- LANDFILL GAS
- MSW

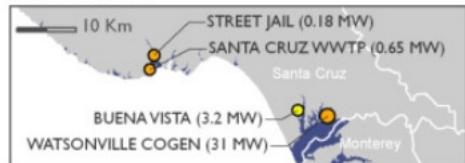
Predicted inundation of 100-year flood with 1.4m Sea Level Rise

Source: Pacific Institute

San Francisco Bay Area



Santa Cruz Area



Los Angeles Area

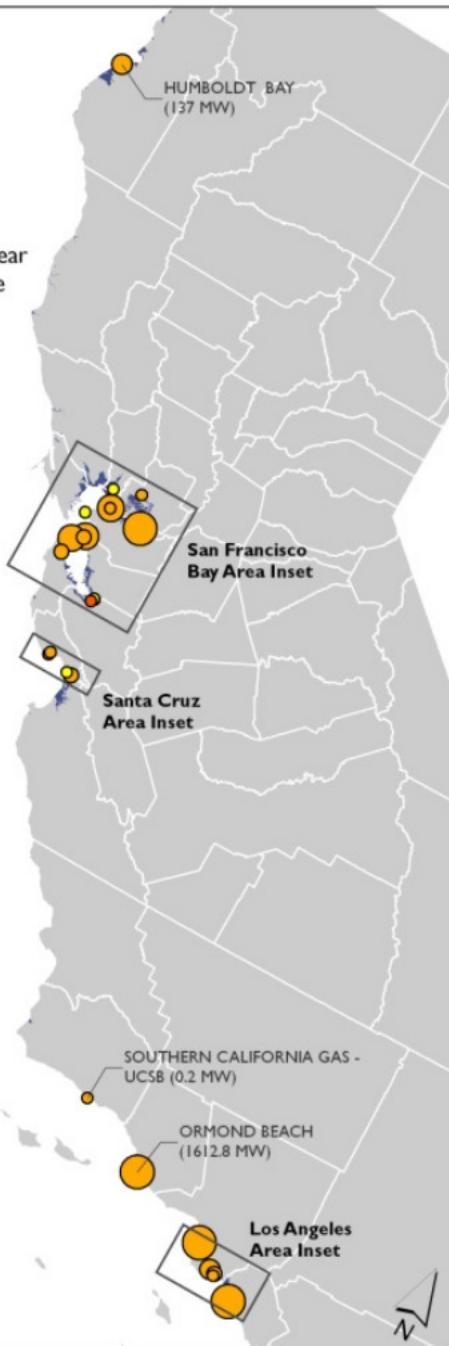
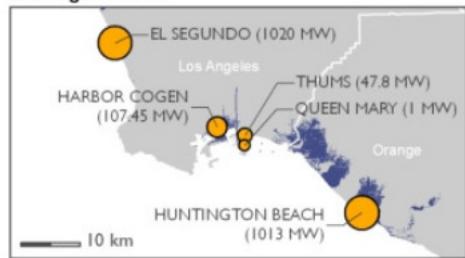


Figure 19. Power Plants Potentially at Risk to a 100-year Flood with 1.4 m Sea Level Rise

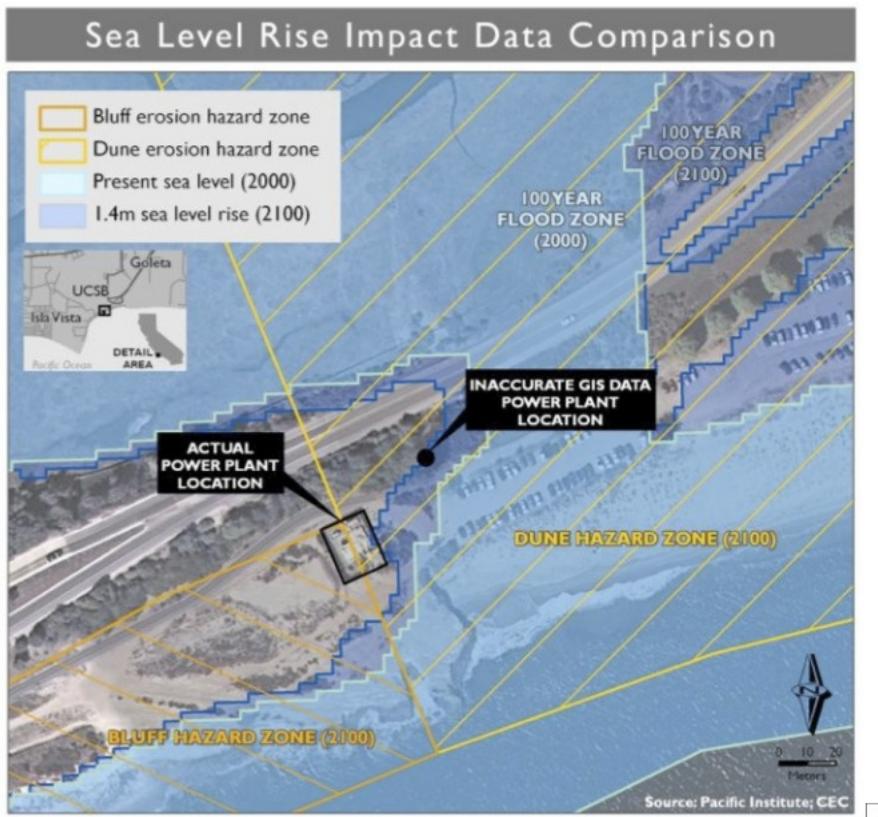


Figure 20. Sea Level Rise Impact Data Comparison

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Impacts on Natural Gas Facilities in the Delta

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Natural Gas Facilities in the Delta

Natural Gas Infrastructure Below Sea Level

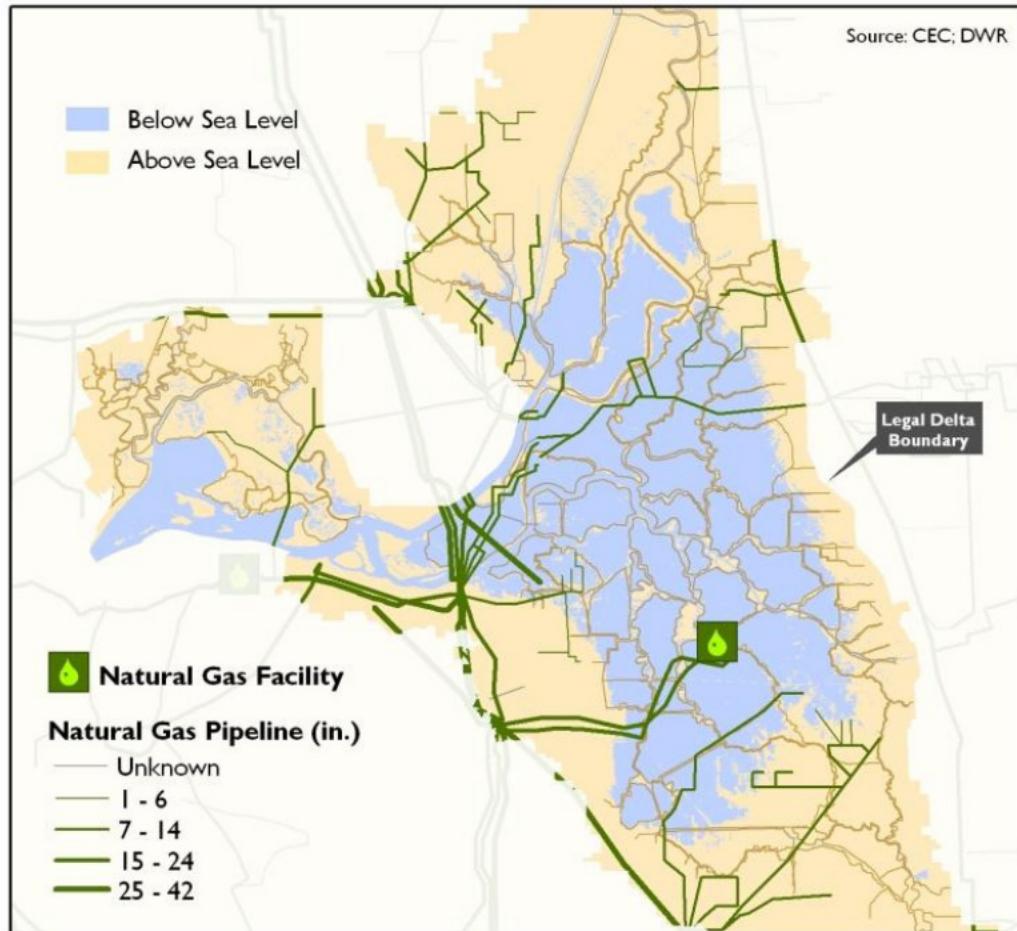
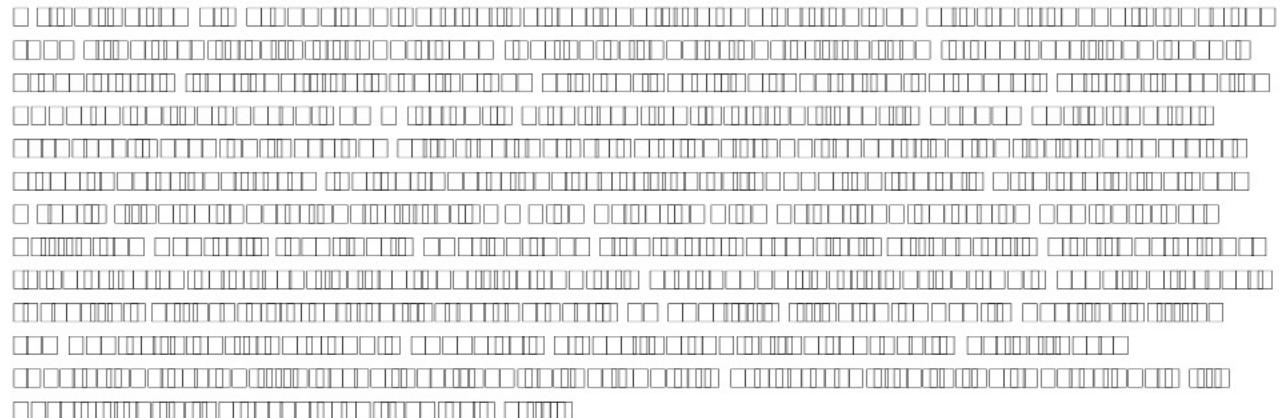


Figure 21. Natural Gas Facilities near Sea Level in the Sacramento-San Joaquin River Delta

Impact of Sea Level Rise on Substations



Substations Potentially at Risk from Sea Level Rise

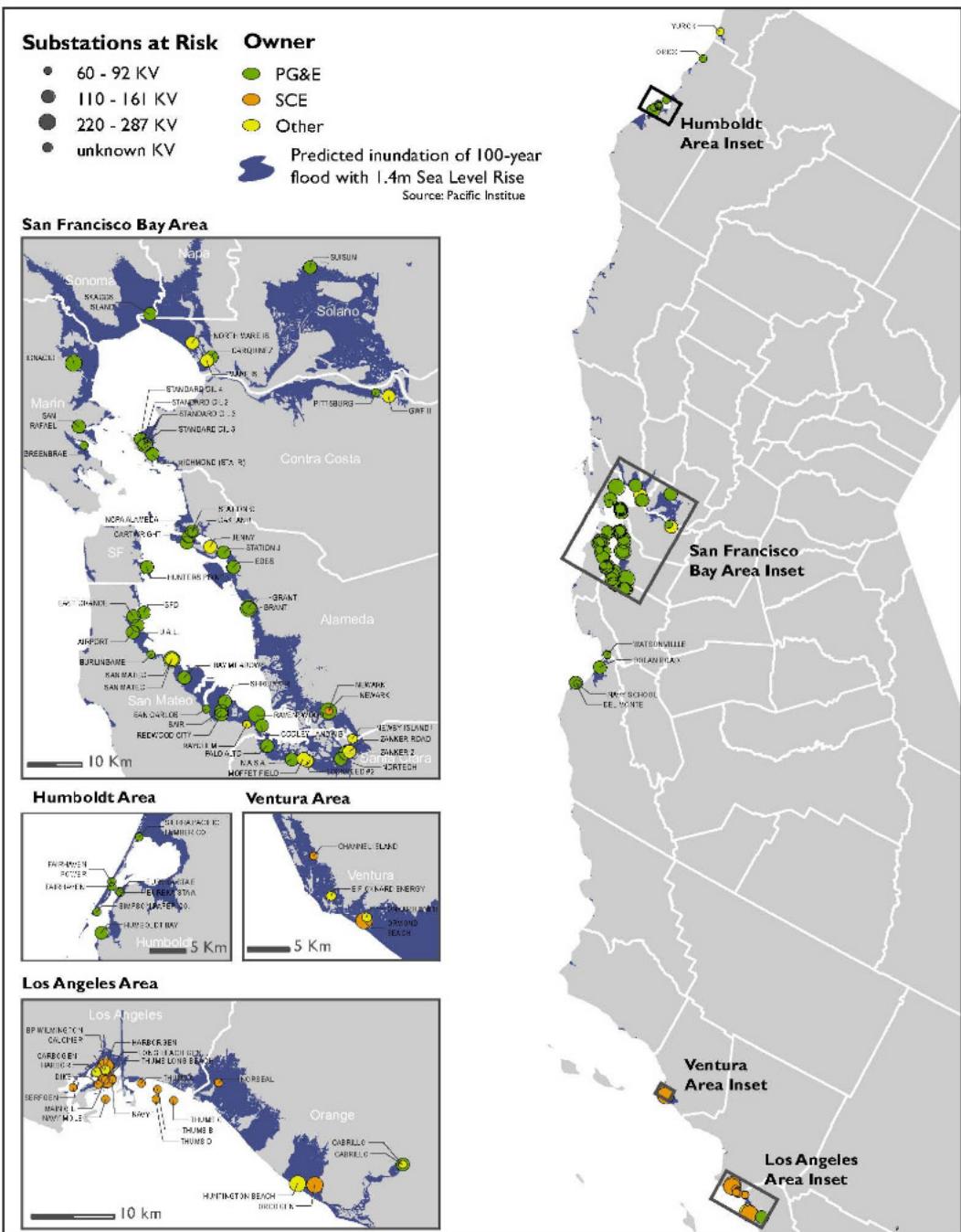


Figure 22. Substations at Risk to a 100-year Flood with a 1.4m Sea Level Rise

Chapter 6: Conclusion

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Chapter 7: References

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APPENDIX A: Literature Review

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Table B-1: Hydroclimatological and Climate Parameters for Select Energy Uses

Hydro-meteorological and/or climate parameter	Select energy uses
Air temperature	Turbine production efficiency, air source generation potential and output, demand (cooling/heating), demand simulation/modeling, solar PV panel efficiency
Rainfall	Hydro-generation potential and efficiency, biomass production, demand, demand simulation/modeling
Wind speed and/or direction	Wind generation potential and efficiency, demand, demand simulation/modeling
Cloudiness	Solar generation potential, demand, demand simulation/modeling
Snowfall and ice accretion	Power line maintenance, demand, demand simulation/modeling
Humidity	Demand, demand simulation/modeling
Short-wave radiation	Solar generation potential and output, output modeling, demand, demand simulation/modeling
River flow	Hydro-generation and potential, hydro-generation modeling (including dam control), power station cooling water demands
Coastal wave height and frequency, and statistics	Wave generation potential and output, generation modeling, off-shore infrastructure protection and design
Sub-surface soil temperatures	Ground source generation potential and output
Flood statistics	Raw material production and delivery, infrastructure protection and design, cooling water demands
Drought statistics	Hydro-generation output, demand
Storm statistics (includes strong winds, heavy rain, hail, lightning)	Infrastructure protection and design, demand surges
Sea level	Offshore operations, coastal energy infrastructure

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References

APPENDIX B: Methodological Overview

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Importing Energy Infrastructure Data and Merging Local Maximum Temperature Projections

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Quantifying Likelihood of Temperature Projections

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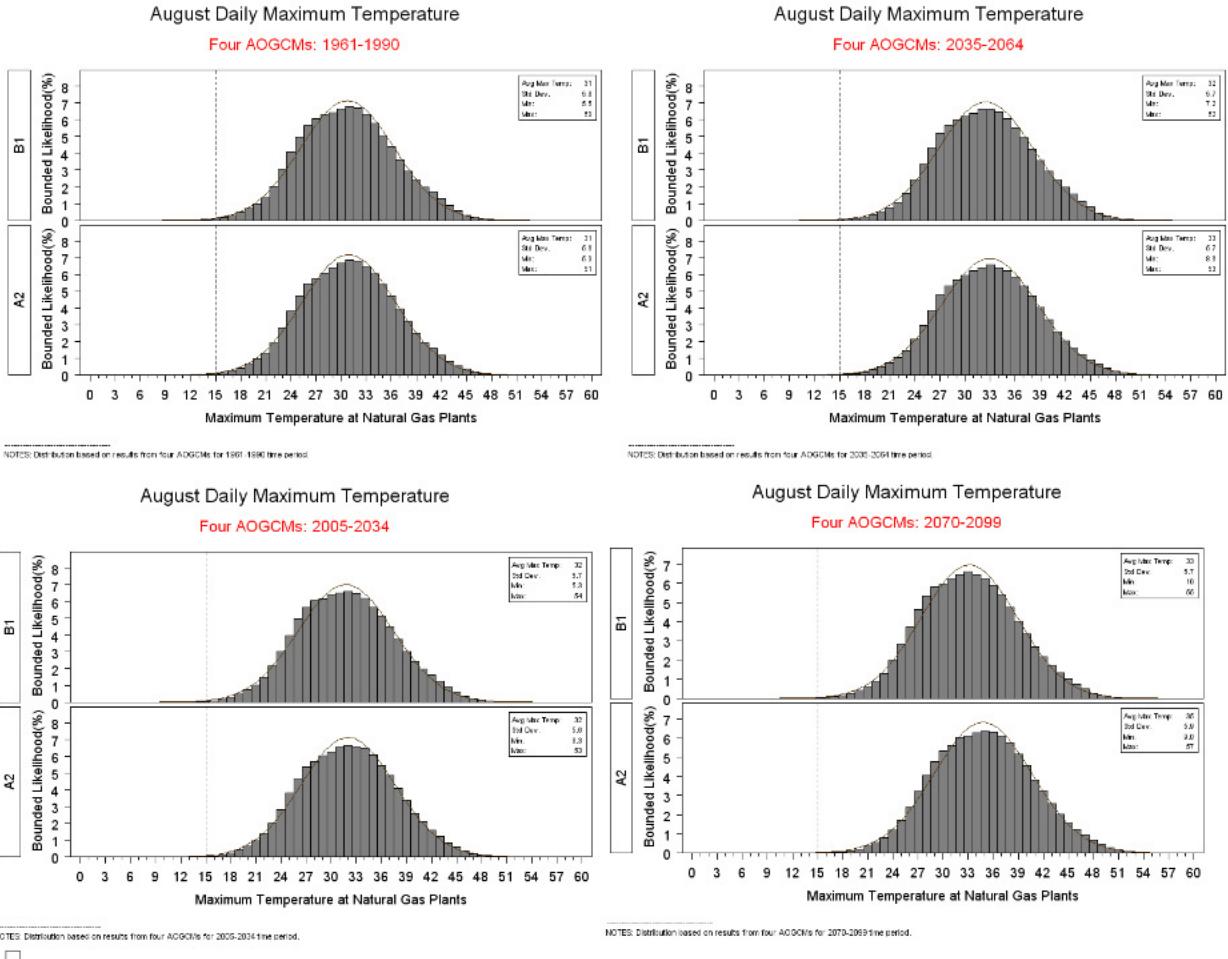


Figure B-1. Projected Range of August Daily Maximum Temperatures at California's Natural Gas-fired Power Plants



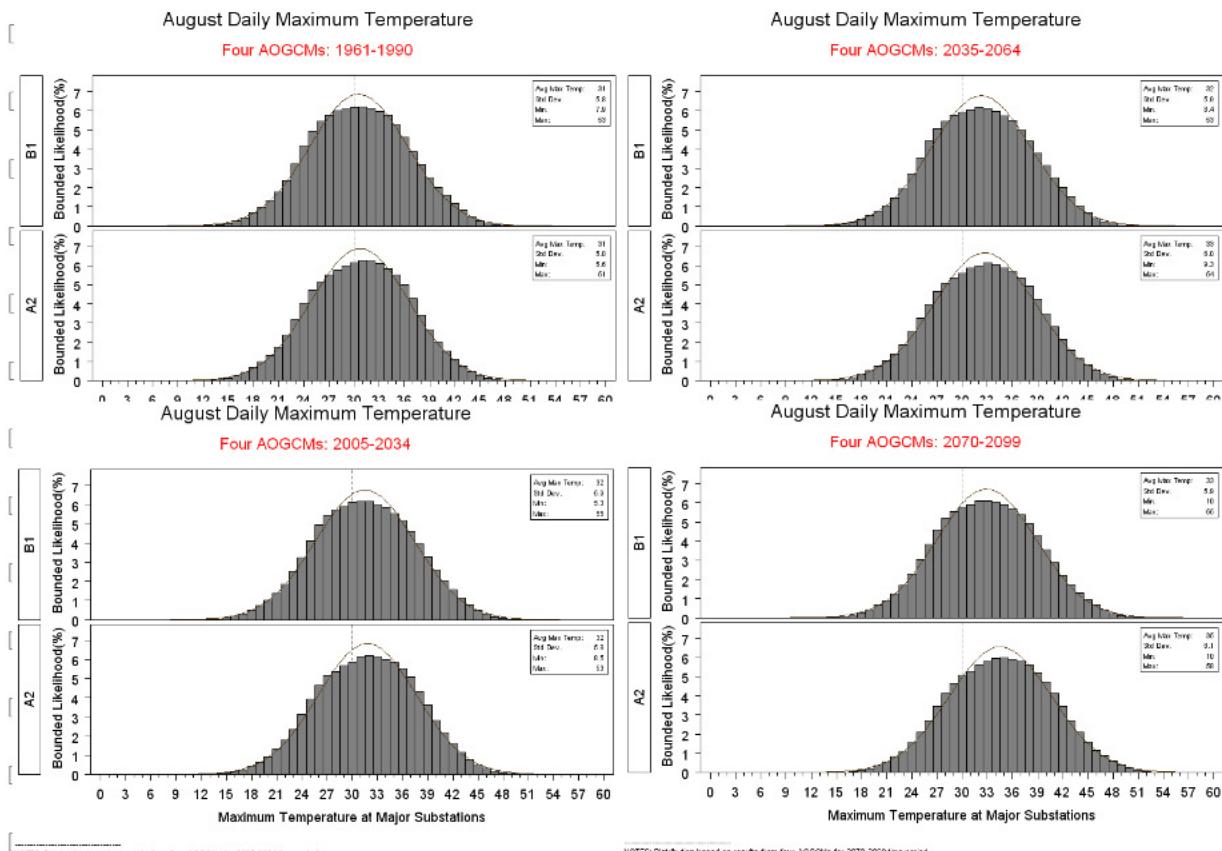


Figure B-2. Projected Range of August Daily Maximum Temperatures at California's Major Substations

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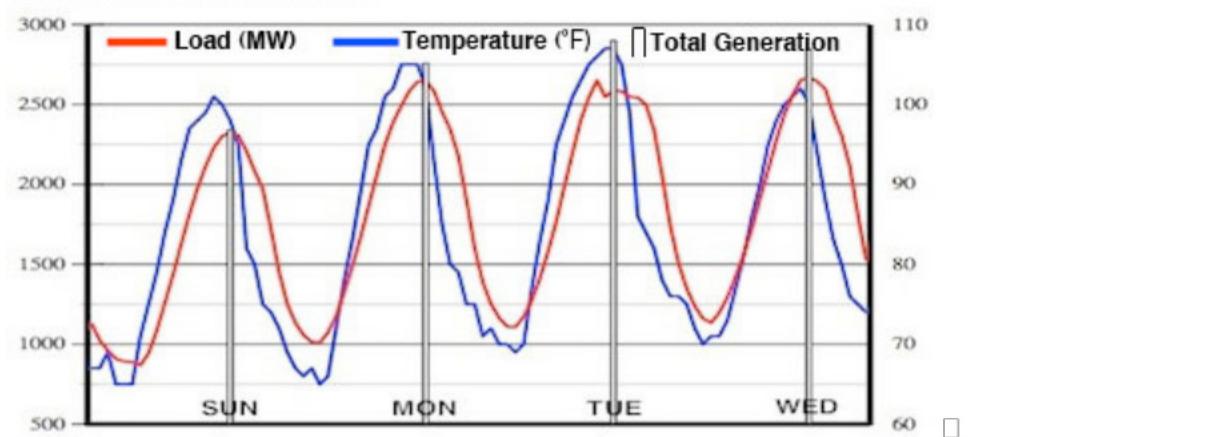
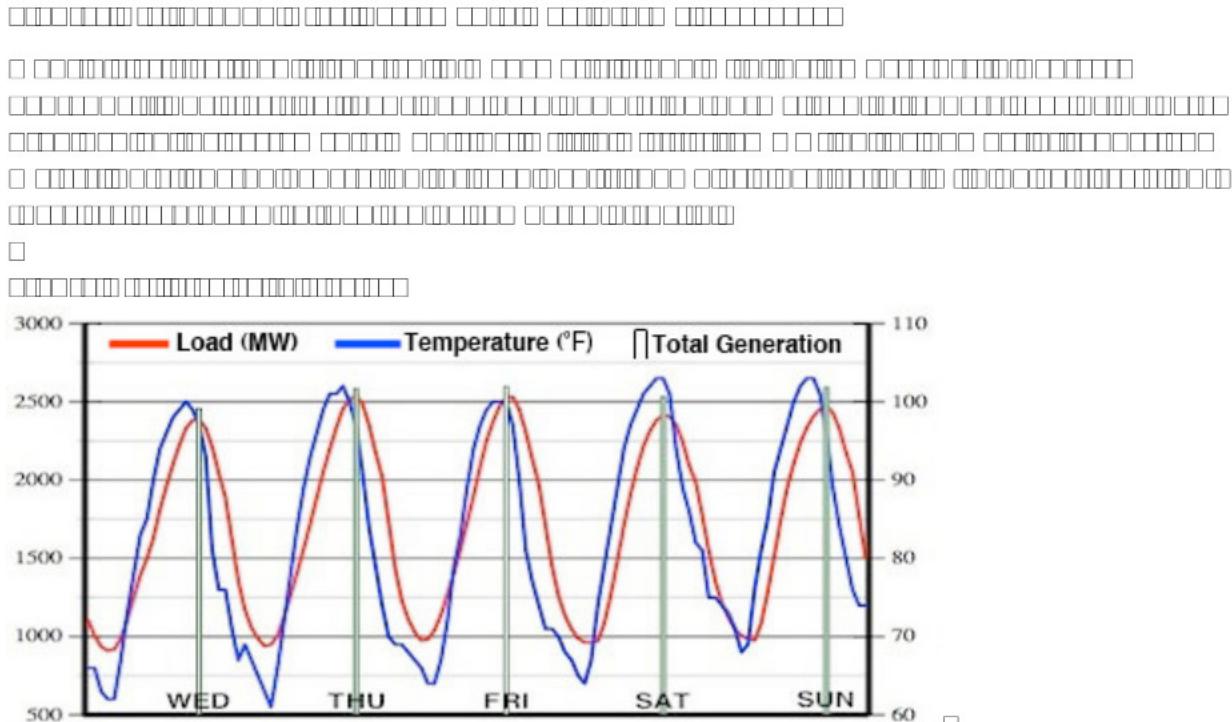
APPENDIX C: The Effect of Heat Storms on Electricity Demand

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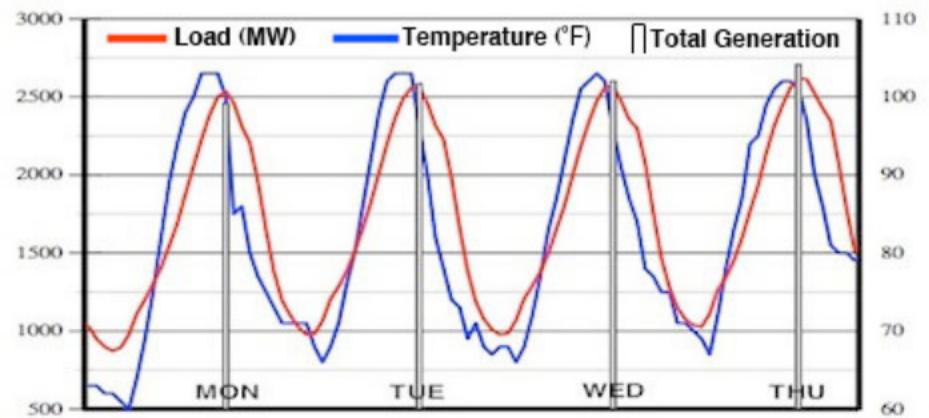
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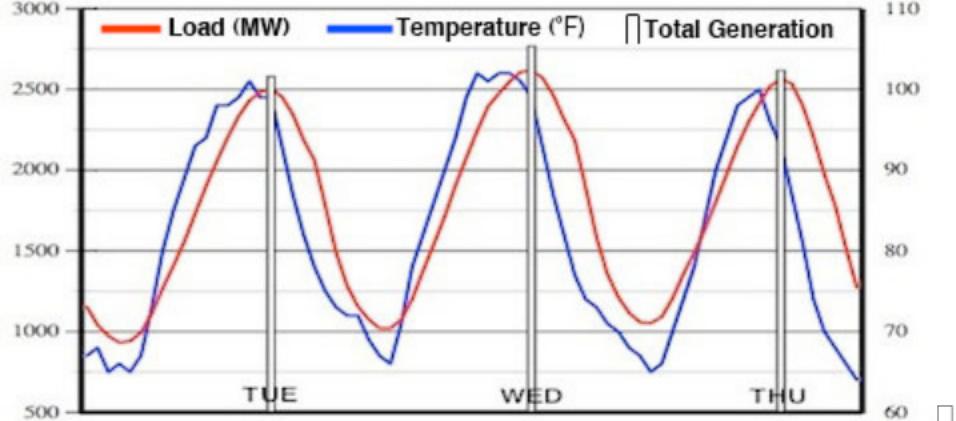
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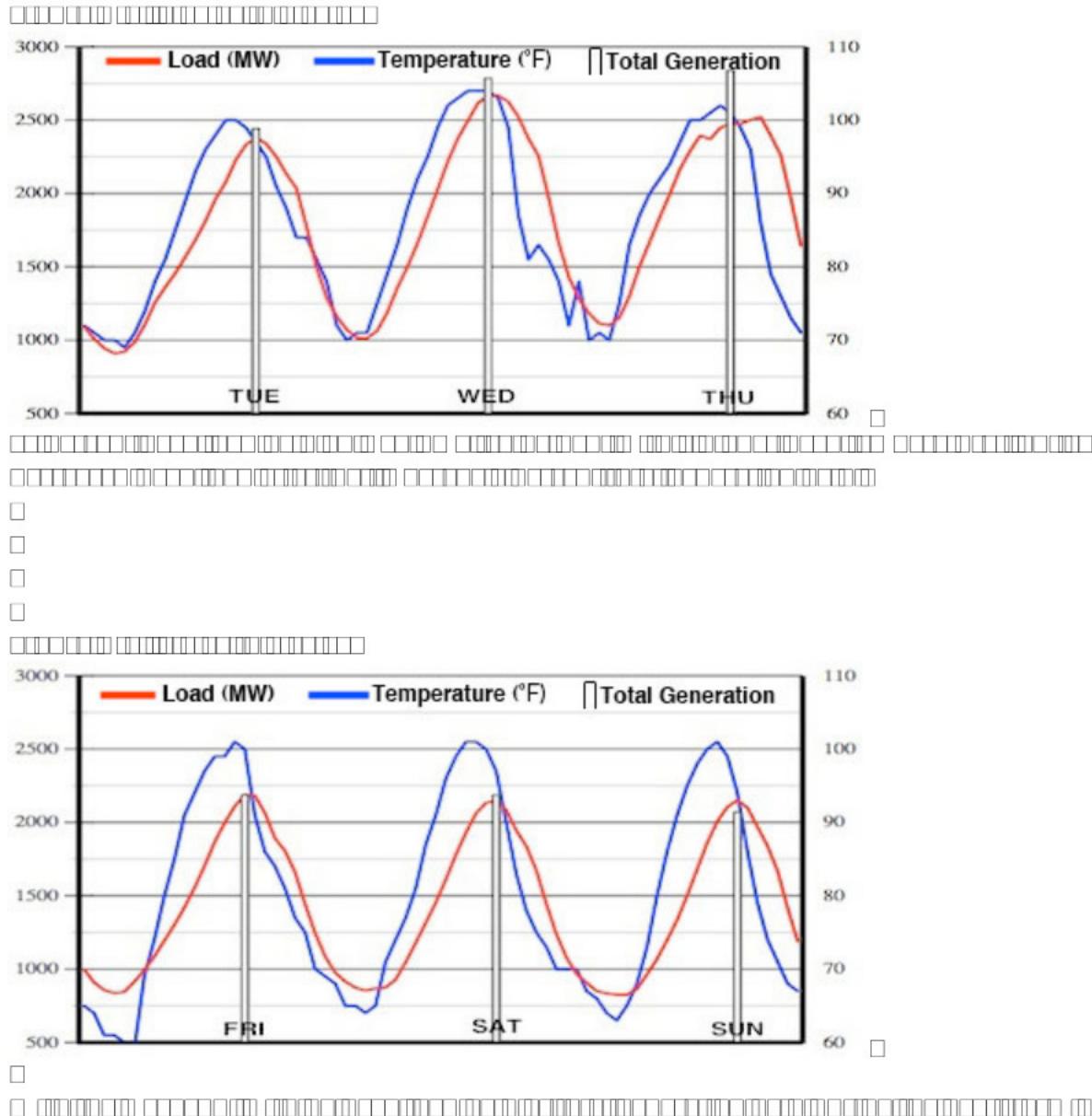
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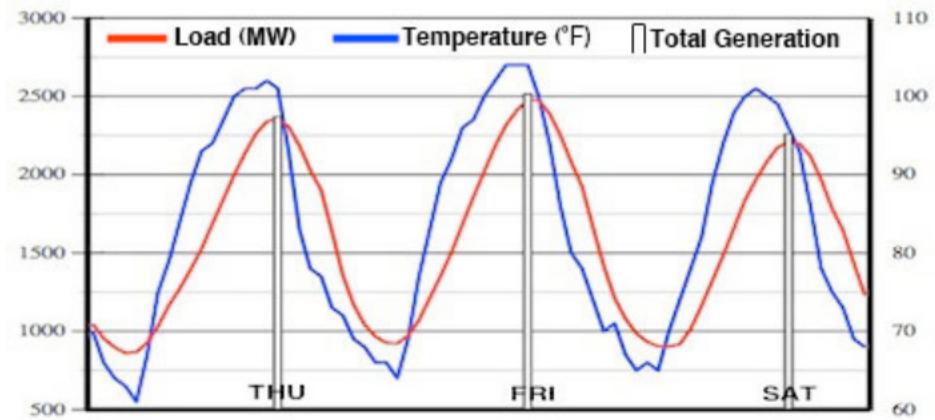
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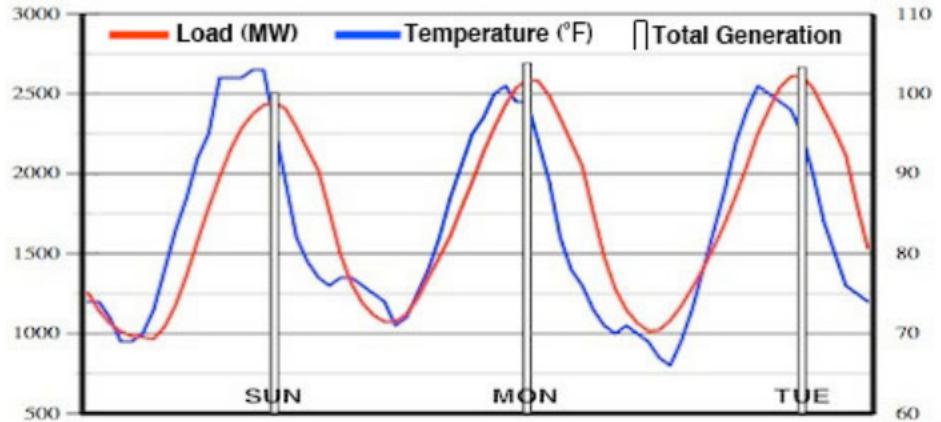
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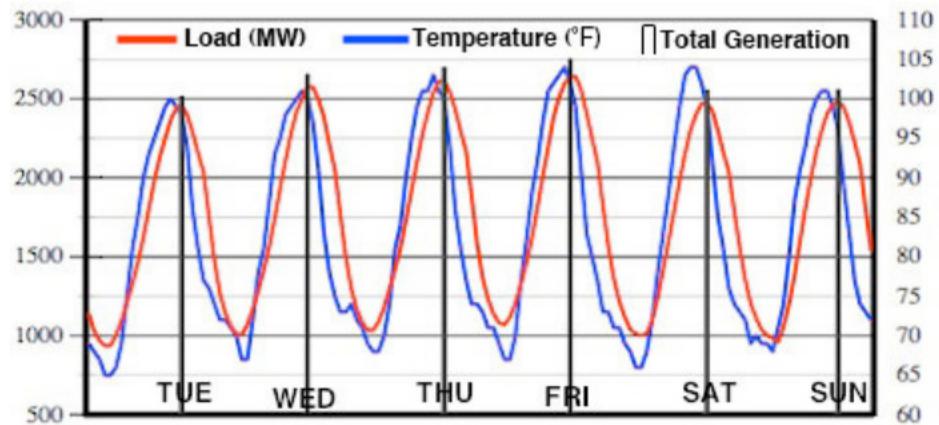


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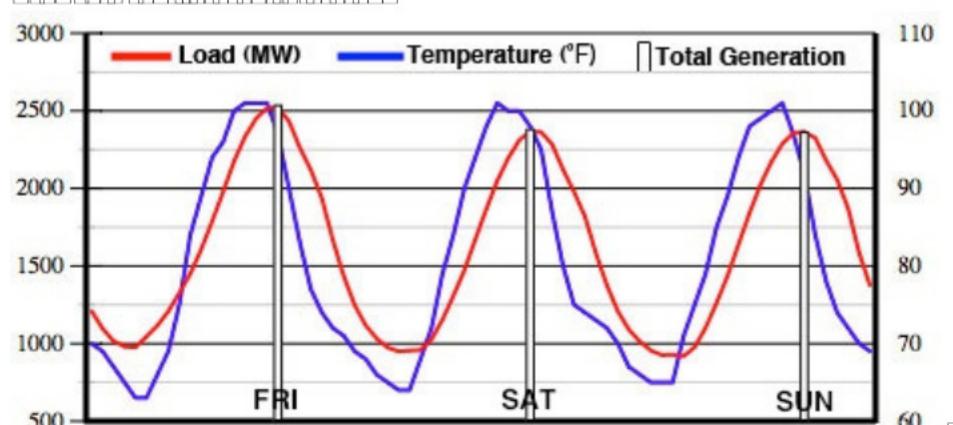
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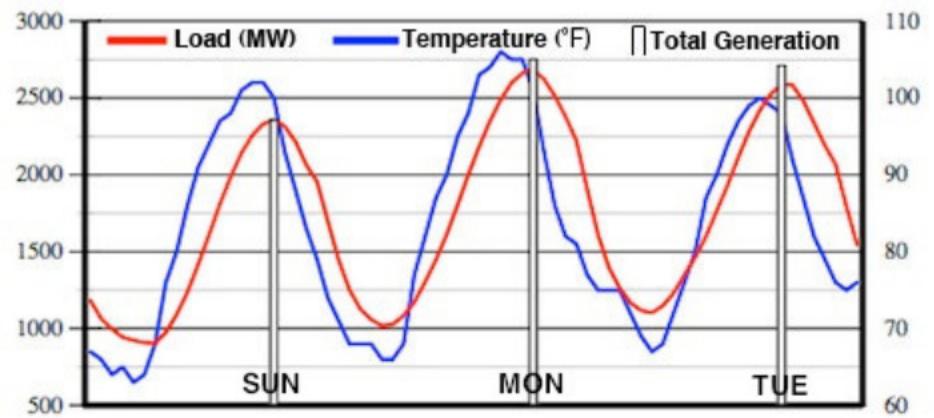
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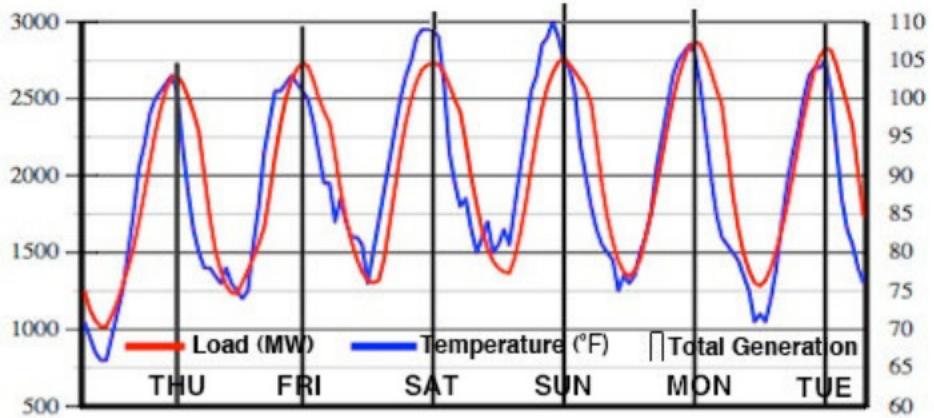
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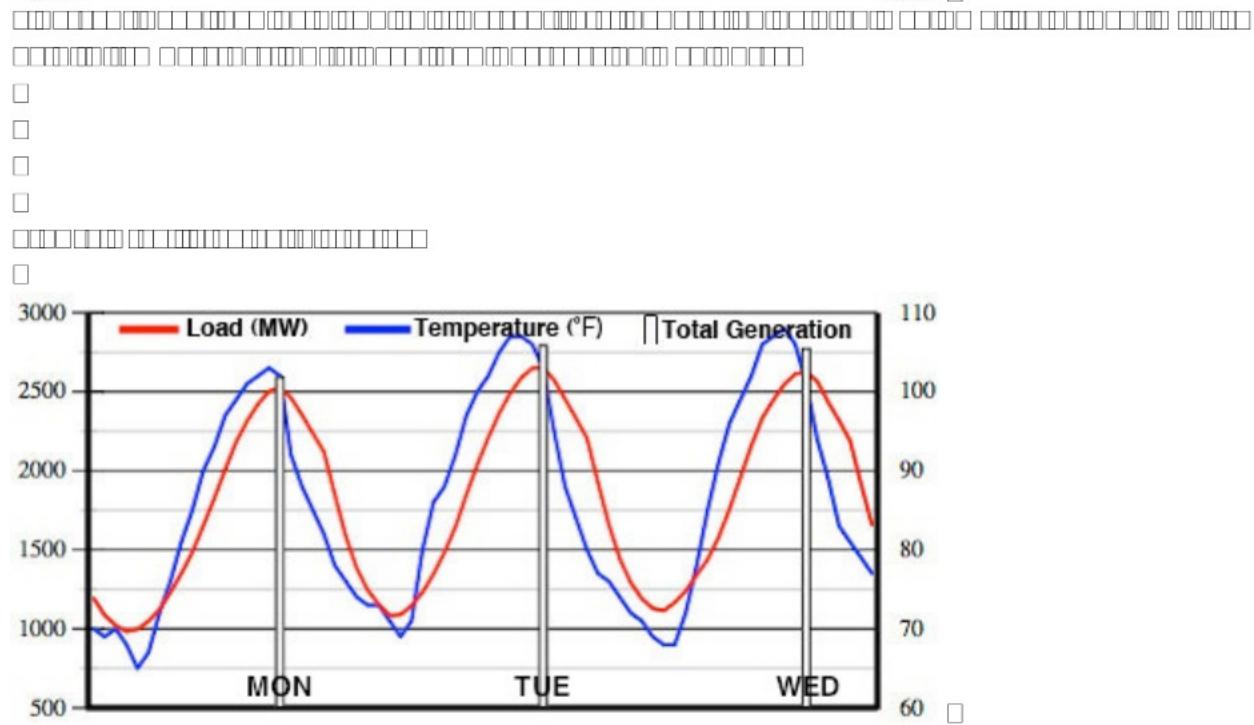
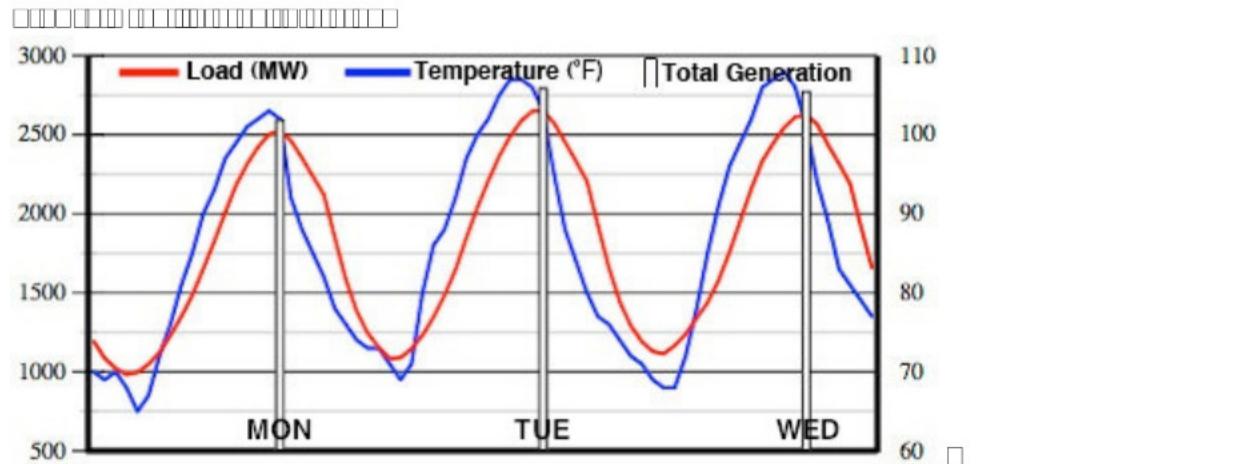


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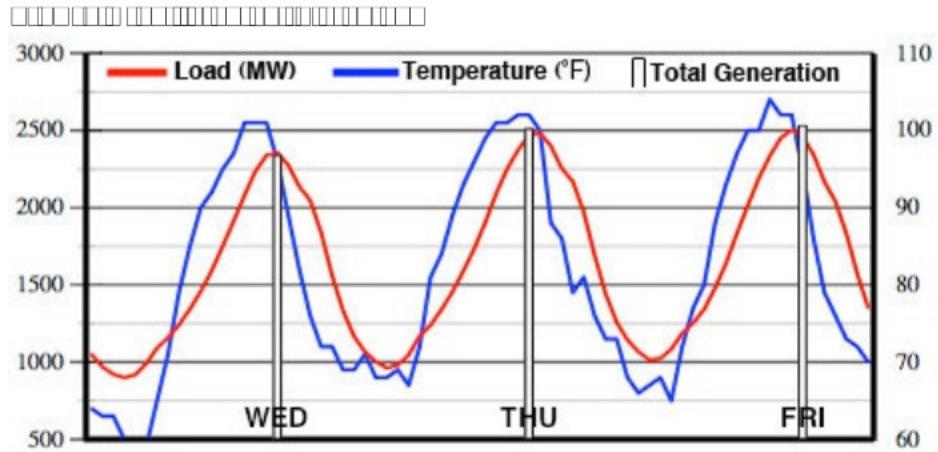
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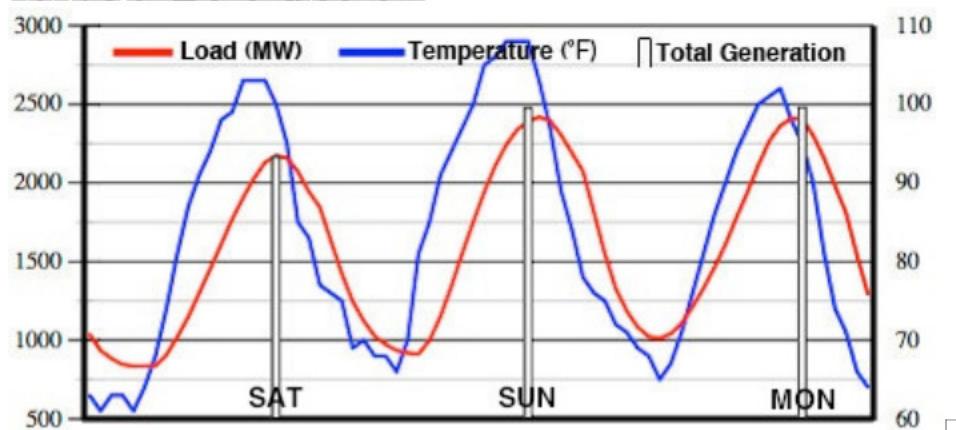
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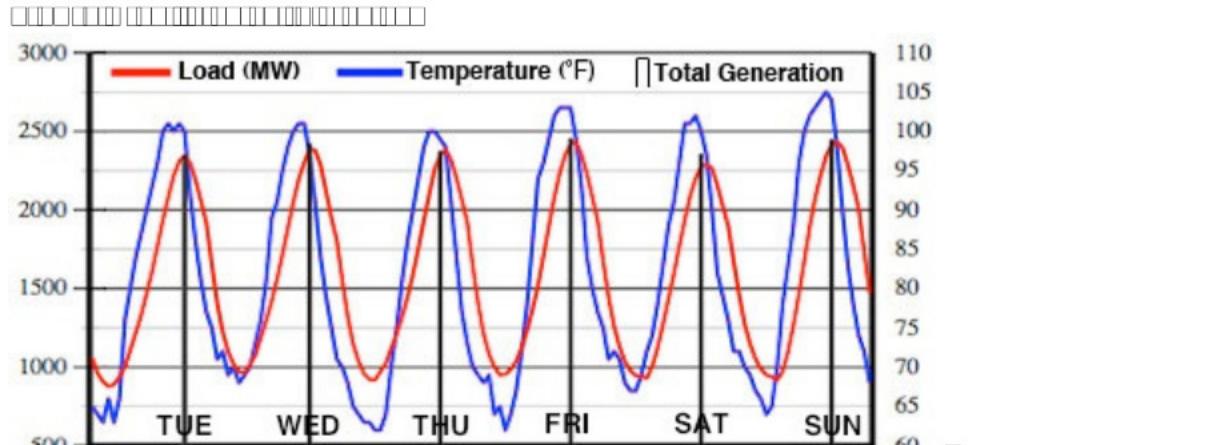
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